[redacted]

RA018-001-1

OFFICE OF MANNED SPACE FLIGHT

APOLLO PROGRAM

(NASA-TM-X-61628) APOLLO RELIABILITY AND QUALITY ASSURANCE PROGRAM. APPENDIX C - APOLLO SATURN 504 MISSION RELIABILITY ANALYSIS QUARTERLY STATUS REPORT (National Aeronautics and Space Administration) 300 p

N79-76622

Unclas

00/38 11116

APOLLO SATURN 504

MISSION RELIABILITY ANALYSIS

APPENDIX C

TO

APOLLO RELIABILITY AND QUALITY ASSURANCE PROGRAM

QUARTERLY STATUS REPORT (U)

CLASSIFICATION CHANGE

TO UNCLASSIFIED

By authority of

Changed by

Date

THIRD QUARTER 1965

8 OCTOBER 1965

FF No. 602(A)

(ACCESSION NUMBER) (THRU)

(PAGES) (CODE)

(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

AVAILABLE TO NASA OFFICES AND NASA RESEARCH CENTERS ONLY

PREPARED BY APOLLO RELIABILITY & QUALITY ASSURANCE OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, D.C. 20546

[redacted]

3238-C

~~C63-544~~

[redacted]

RA018-001-1

Copy 17
of 225 Copies

APOLLO-SATURN 504

MISSION RELIABILITY ANALYSIS

APPENDIX C

TO

APOLLO RELIABILITY AND QUALITY ASSURANCE PROGRAM

QUARTERLY STATUS REPORT (U)

THIRD QUARTER 1965

8 October 1965

~~Gr[redacted] 4~~
~~Downgra[redacted]ar Intervals;~~
~~Declassi[redacted]~~
~~D[redacted]200.10~~

~~Th[redacted] document co[redacted]rmation affecting [redacted] defense of the [redacted]ed States w[redacted]in the [redacted]the E[redacted]spionage La[redacted] 18, U.S.[redacted]., Sectio[redacted] t[redacted]or the revel[redacted]ion of [redacted]contents in any man[redacted] unauthorized person is [redacted]ited by law.~~

Prepared by

Apollo Reliability and Quality Assurance Office
National Aeronautics and Space Administration
Washington, D.C. 20546

[redacted]

[redacted]

TABLE OF CONTENTS

[redacted]

TABLE OF CONTENTS (Cont.)

[redacted]

LIST OF ILLUSTRATIONS

[redacted]

[redacted]

LIST OF ILLUSTRATIONS (Cont.)

[redacted]

C.1 INTRODUCTION

C.1.1 PURPOSE

This Appendix is published to report in detail the reliability analysis and quantitative predictions of crew safety and mission success for the Apollo-Saturn 504 Manned Lunar Landing Mission. These are set forth, together with qualitative engineering review comments and recommendations, in this Appendix to the Quarterly Status Report dated 8 October 1965 and prepared by the Apollo Reliability and Quality Assurance Office of NASA, Washington, D.C.; in accordance with Apollo Program Development Plan (NPC-500), Section 10.6, and the Apollo Reliability and Quality Assurance Program Plan (NPC-500-5), Section 4.

C.1.2 ORGANIZATION OF THIS APPENDIX

Section C.1, this Introduction, describes the considerations and methodology employed in making the quantitative evaluations reported in this Appendix.

Section C.2 is a summary which presents a brief recapitulation of the most significant reliability analyses which were made of

Crew Safety and Mission Success	(Section C.3)
Launch Vehicle Reliability	(Section C.4)
Space Craft Reliability	(Section C.5)
Ground Operational Support System	(Section C.6)

Each of these Sections, in turn, begins with a summary statement of present estimates of contribution to mission unreliability for each of these major mission elements, followed by a detailed presentation of reliability estimates for the various components, subsystems, systems, stages and phases of these major elements.

C.1.3 THE RELIABILITY CONCEPT

Recognizing that there can be no actual launch of a manned space vehicle without full assurance of crew safety and mission success, the Apollo Program Office established standards of reliability for all phases of the programs. This Appendix is concerned with the prediction of mission success and crew safety. In this context, reliability is defined as:

> "The probability that system, subsystem, component or part will perform its required function under defined conditions at a designated time and for a specified operating period" (August 1963 Apollo Terminology, NASA SP-6001)

Over the past few years, reliability prediction techniques have clearly demonstrated their value to the military hardware field, particularly in the newly developing space technology. In addition to highly accurate predictions of reliability, significant cost reduction possibilities can come from reliability analyses, particularly in the design stage. It should be emphasized, however, that the benefits arising out of reliability analysis can be realized only if the scope of the analysis is inclusive and supported by an adequate data base. The input requirements for a valid reliability study are severe. Confidence in the model output is closely related to the quality, validity, and accuracy of the input data supplied.

To assure that the established goals of high reliability will be met, NASA requires that all contractors perform rigorous reliability analyses as part of their contractual requirements. The data from reliability analyses is furnished by contractors to the NASA Center (MSFC, MSC, or KSC) concerned with performance of specific contracts. The Centers also conduct related and supplementary reliability analyses. The Center/contractor data is then supplied to the Apollo Reliability and Quality Assurance Office for evaluation by reliability monitors. Reviews of reliability analyses are provided at each level to coordinate and verify all reliability data and activities.

C.1.3.1 Assurance of Uniform Methodology

To assure that the reliability studies conducted at each level are compatible and coordinated, Apollo Program Office policy requires the development and utilization of uniform evaluation techniques and procedures. Toward that end, the Apollo Reliability and Quality Assurance Office sets up review procedures for all levels and provides uniform analytical procedures, such as are set forth in the document "Apollo Reliability Estimation Guidelines."

C.1.4 RELIABILITY ESTIMATION

C.1.4.1 Obtaining Quantitative Values

Mission reliability estimates are made by utilizing the data and processing techniques involved in:

1. Apportionment, which is an assignment of responsibility to contractors for achieving certain defined, reliability goals.
2. Predictions, which are estimates of the best performance expectancies, as derived from past performance data and updated state-of-the-art accomplishments.
3. Assessments, which are measurements derived from actual performance tests of equipments.

The values evolving from these assigned goals, estimated performances, and test measurements are subjected to analytical techniques utilizing probability theory, statistical analysis, and models which simulate actual performance of parts, assemblies, subsystems, and systems. The analysis yields a quantitative evaluation of reliability which, when properly coupled with qualitative engineering evaluations, provide an effective means for gauging the potential reliability of the mission.

C.1.4.2 Mission Reliability Profiles

Prior to the construction of the models, the specific in-flight mission phases are analyzed to relate the functioning of the parts, assemblies, subsystems and systems to the actual requirements of crew performance, mission events, operation constraints, trajectories, environments, timed events and possible contingencies. In making this analysis for the Apollo-Saturn 504 Mission a document designated as Design Reference Mission Reliability Profile was developed (Reference 3). This document utilizes data from the Design Reference Mission (Reference 2) prepared by the Apollo Mission Planning Task Force. This Profile was sent to reliability personnel at NASA Headquarters and Centers. Useful comments were received from Bellcomm and the Marshall Space Flight Center. A simplified version of the Profile is shown in Figure C.1-1.

APOLLO SATURN 504 MANNED LUNAR LANDING MISSION

Mission Phase	Mission Events Defining Subphase	Time***	Subphase Designator and Number
Prelaunch Phase	S-IC Ignition Command	0 0 6	1 S-IC Ignition Cycle
Earth Ascent Phase	Liftoff (Hold Down) Release)	0 0 0	2 S-IC Boost I
	t* + 50 Seconds	0 0 50	3 S-IC Boost II
	t + 100 Seconds	0 1 40	4 S-IC Boost III
	S-IC Inboard Engine c.o.	0 2 25	5 S-IC/S-II Separation
	S-II Booster Operation at 90% Thrust	0 2 30	6 S-II Boost I
	t + 410 Seconds	0 6 50	7 S-II Boost II
	S-II Engine c. o. Command	0 9 02	8 S-II/S-IVB Separation
	S-IVB Booster Operation at 90%	0 9 07	9 S-IVB Boost I
Earth Orbit Phase	S-IVB Engine Cutoff	0 11 52	10 S-IVB Purge Period
	Enter Darkness 1	0 47 07	11 Earth Orbit Coast I
	Enter Darkness 2	2 15 07	12 Earth Orbit Coast II
Translunar Injection Phase	S-IVB Ignition Command	3 00 43	13 S-IVB Boost I
	S-IVB Ignition ($V/V_1 = 0.9$)	3 04 03	14 S-IVB Boost II
Initial Translunar Coast Phase	S-IVB Engine Cutoff	3 05 59	15 Transposition Preparation
	Initiate CSM/LEM Separation	3 20 58	16 CM Docking Maneuvers
	Docking Complete	3 47 58	17 S-IVB Jettison Activities
S-IVB Jettison to Lunar Orbit Insertion Phase	S-IVB Jettison Complete	3 50 58	18 Translunar Coast I
	SM Ignition	5 06 58	19 Midcourse Correction I
	SM Cutoff	5 06 18	20 Translunar Coast II
	t + 15 Hours	15 00 00	21 Translunar Coast III

Primary Abort**	Secondary Abort
LES Abort	(no secondary abort capability)
0 2 50 — Suborbital Abort/AMR Landing	S-IVB + SPS Abort to Orbit
0 8 10	S-IVB Abort to Orbit
	SPS Abort to Orbit
SPS Abort to Orbit	Suborbital Abort/Indian Ocean Landing
SM-SPS De-Orbit to Planned Landing Area	SM-RCS De-Orbit to Planned Landing Area
SM-SPS De-Orbit to Indian Ocean	(no secondary abort capability)
SM-SPS Abort to Planned Landing Area	LEM Abort to Planned Landing Area

Mission Phase	Mission Events Defining Subphase	Time***	Subphase Designator and Number
S-IVB Jettison to Lunar Orbit Insertion Phase (cont)	t + 25 Hours	25 00 00	22 Translunar Coast IV
	t + 35 Hours	35 00 00	23 Translunar Coast V
	t + 45 Hours	45 00 00	24 Translunar Coast VI
	SM Ignition	55 30 00	25 Midcourse Correction II
	SM Cutoff	55 30 12	26 Translunar Coast VII
	SM Ignition	63 15 04	27 Midcourse Correction III
	SM Cutoff	63 15 10	28 Terminal Translunar Coast
Lunar Orbit Insertion Phase	SM Ignition (Lunar Orbit Insertion)	64 15 04	29 SM L.O.I. Burn I
	SM Ignition + 100 Sec	64 16 44	SM L.O.I. Burn II
	SM Ignition + 130 Sec	64 17 14	31 SM L.O.I. Burn III
	SM Ignition + 160 Sec	64 17 44	32 SM L.O.I. Burn IV
Lunar Orbit Coast to LEM Separation Phase	SM Cutoff	64 20 56	33 Lunar Orbit Coast
	LEM Crew Boarding	65 47 00	34 LEM Descent Preparation
CSM Solo/ LEM Separation and Descent Phase	LEM/CSM Separation Command	68 04 14	35 LEM/CSM Separation
	LEM Ignition Command	68 24 14	36 LEM Low Thrust Burn I
	LEM Maximum Thrust Command	68 24 42	37 LEM Maximum Thrust Burn I
	LEM Cutoff	68 24 48	38 LEM Coast
	LEM Ignition Command	69 22 53	39 LEM Terminal Thrusting I
	LEM Ignition Command +250 Seconds	69 27 03	40 LEM Terminal Thrusting II
See Next Page	Hover Point Attainment	69 31 18	41 LEM Hover Burn

Primary Abort**	Secondary Abort
SPS Abort to Planned Landing Area	LEM Circumlunar Abort to Planned Landing Area
SPS Circumlunar Abort to Planned Landing Area	
SPS Hyperbolic Trajectory Abort	LEM Hyperbolic Trajectory Abort
SPS Minimum Reaction Time Abort	LEM Minimum Reaction Time Abort
SPS Elliptic Abort	LEM Elliptic Abort
SPS Lunar Orbit Abort	LEM Lunar Orbit Abort
LEM-RCS Return to Rendezvous	LEM Descent Engine Return to Rendezvous
LEM Descent Engine Return To Rendezvous	LEM Ascent Engine Return To Rendezvous
LEM Descent/Ascent Return to Rendezvous	LEM Ascent Engine Return to Rendezvous
69 29 23 — LEM Descent/Ascent Engine Abort to Parking Orbit	LEM Ascent Engine Abort to Parking Orbit

* t denotes instant of liftoff.

** All primary abort modes were available for use in this analysis. The secondary abort modes are representative of those under consideration for future estimates.

(hatched) Indicates no secondary abort capability exists at this time.

*** Time: Hours, Minutes, Seconds

Figure C.1-1. Reliability Mission Profile, (Abbrev
(Page 1 of 2)

APOLLO SATURN 504 MANNED LUNAR LANDING MISSION

Mission Phase	Hover to Touchdown and Lunar Stay Phase										LEM Ascent Phase								
Mission Events Defining Subphase Time***	Touchdown 69 32 23	Commander Exits LEM ** 71 01 03	System Engineer Exits LEM 74 07 33	System Engineer Re-enters LEM 77 04 33	Commander Exits LEM 83 30 04	System Engineer Exits LEM 86 37 04	System Engineer Re-enters LEM 89 34 04	Commander Exits LEM 95 59 14	System Engineer Exits LEM 99 09 44	System Engineer Re-enters LEM 102 04 44	LEM Ascent Engine Ignition 104 17 06	T LEM Ascent +367 Seconds 104 23 13	LEM Ascent Engine Cutoff 104 24 09	Start 1st MCC 104 33 09	Complete 1st MCC 104 33 38	Start 2nd MCC 104 47 09	Complete 2nd MCC 104 47 18	Start 3rd MCC 104 57 09	Complete 3rd MCC 104 57 13
Subphase Designator and Number	Post Landing Checkout 42	Lunar Surface Operations I 43	Lunar Surface Operations II 44	Exploration Preparation I 45	Lunar Surface Operations III 46	Lunar Surface Operations IV 47	Exploration Preparation II 48	Lunar Surface Operation V 49	Lunar Surface Operation VI 50	Prelaunch Checkout 51	LEM Boost I 52	LEM Boost II 53	LEM Coast I 54	LEM Midcourse Correction I 55	LEM Coast II 56	LEM Midcourse Correction II 57	LEM Coast III 58	LEM Midcourse Correction III 59	LEM Coast IV 60

	42–51	52–53	54–60
Primary Abort*	(A) Once during every revolution of the "CM, "a "Direct Ascent Abort" opportunity exists (time duration 1 min 20 sec). (B) A "LEM Parking Orbit Abort" must be initiated during the time when the launch window for A is not available.	LEM Abort to Parking Orbit	CSM Rescue Of LEM

	42–52	53	54–60
Secondary Abort	(hatched)	LEM RCS Abort to Parking Orbit	(hatched)

Mission Phase	LEM Ascent Phase (Cont.)						Lunar Orbit Coast to Transearth Injection Phase			Trans-earth Injection Phase	Transearth Coast Phase							Entry Phase		Parachute Descent Phase	Retrieval Phase	
Mission Events Defining Subphase	Begin 1st Rendezvous Thrust 105 11 00	Complete 1st Rendezvous Thrust 105 11 05	Begin 2nd Rendezvous Thrust 105 15 13	Complete 2nd Rendezvous Thrust 105 16 34	Begin 3rd Rendezvous Thrust 105 19 09	Complete 3rd Rendezvous Thrust 105 19 16	LEM/CSM Hard Contact 105 33 46	Crew Transfer Complete 106 09 36	LEM Jettison Command 106 14 16	SM Ignition Command 109 08 13	SM Cutoff 109 09 56	Start 1st MCC Thrusting 129 09 56	Complete 1st MCC Thrusting 129 10 01	Start 2nd MCC Thrusting 174 09 56	Complete 2nd MCC Thrusting 174 09 59	Start 3rd MCC Thrusting 197 15 34	Complete 3rd MCC Thrusting 197 15 36	Jettison SM 198 00 34	Forward Heatshield Deployment Command 198 25 59	Drogue Chute Deployment Command 198 26 01	Touchdown 198 33 08	Initiate Retrieva Operatio 198 43 3
Subphase Designator and Number	Rendezvous Maneuver I 61	Rendezvous Coast I 62	Rendezvous Maneuver II 63	Rendezvous Coast II 64	Rendezvous Maneuver III 65	LEM/CSM Docking 66	Crew/ Equipment Exchange 67	Post Docking Activities 68	T.E.I. Preparation 69	SM Burn I 70	Transearth Coast I 71	Midcourse Correction IV 72	Transearth Coast II 73	Midcourse Correction V 74	Transearth Coast III 75	Midcourse Correction VI 76	Terminal Transearth Coast 77	Entry Range Control Maneuvers 78	Recovery Preparation 79	Impact Preparation 80	Retrieval Preparation 81	

	61–66	67–69	70	71–72	73–81 (from 139 10 01)
Primary Abort**	CSM Rendezvous	SPS Early Injection to Planned Landing Area	SPS Injection Abort	SPS Abort to Planned Landing Area	NO PRIMARY ABORT CAPABILITY
Secondary Abort	(hatched)	(hatched)	(hatched)	(hatched)	(hatched)

* All primary abort modes were available for use in this estimate.
The secondary abort modes are representative of those under consideration for future estimates.

** Since this time line only reflects those events which define a subphase, some obvious events such as "Commander Enters LEM" are not delineated.

(hatched) Indicates no secondary abort capability exists at this time.

*** Time: Hours, Minutes, Seconds

Figure C.1-1. Reliability Mission Profile, (Abbreviated) (Page 2 of 2)

The Profile as now constituted provides a base for a simulation of the Apollo-Saturn 504 Mission. However, more accurate modeling will be accomplished upon receipt of additional input data from contractors, Centers, and the interim flight now scheduled.

C.1.4.3 Mission Ground Rules

The model constructed for simulation of the Apollo-Saturn 504 Mission was subject to a number of constraints, necessary assumptions, and required conformance with established ground rules. Such constraints and assumptions are generally included in the parameters of every model and are dealt with accordingly. For example, although the policies and rules defining the conditions under which the mission will be discontinued have not yet been fully resolved, operational rules and assumptions are representative of those integrated into the model:

1. All Guidance, Navigation and Control equipment must remain operative until the Lunar Excursion Module descent.
2. After LEM descent, no Command Module Guidance or Navigation and Control equipment can be cause for abort until LEM rendezvous and docking have been accomplished.
3. The three fuel cells and all batteries must operate during Earth Orbit phase.
4. An abort is required when another failure in the Service Module Propulsion System would result in complete failure of this system.
5. During the time period from Launch Escape System jettison to S-IVB ignition, a suborbital abort will be the primary abort mode.
6. During the period from S-IVB ignition to Earth Orbital Insertion, an abort-to-orbit will be the primary abort mode.
7. In case of an abort-to-orbit, the deorbit maneuver will be executed at a precise time in order to enter one of the three recovery areas.
8. The Service Module with a maximum ΔV of 10,000 FPS provides the only propulsion function capability for returning to earth from a translunar or lunar vicinity abort.
9. Only one type of abort was considered for each given time point in the mission. The abort trajectory was calculated for the minimum return time to reach the planned landing area.

10. Any abort initiated on the lunar surface was calculated on the basis of an assumed launch at the optimum time (window) for rendezvous with the Command Module.

The operational rules listed below were integrated into the model:

1. The crew has the primary responsibility for decisions during the mission.
2. The prime mode for vehicle control is automatic, but crew members control the LEM during final touchdown and the terminal docking maneuver.
3. The prime mode for attitude control is automatic.

C.1.4.4 <u>Logic Diagrams</u>

The complex relationships and interfaces which act upon mission reliability are depicted in logic diagrams to facilitate study and analysis. These diagrams depict in sequences all the possible events leading to the success or failure of the mission. Included in the diagrams are sequences built into the system to provide alternatives for defined contingencies. Examples of a logic diagram and a more detailed explanation of their construction and application can be found in Apollo Estimation Guidelines, prepared by the Apollo Reliability and Quality Assurance Office of NASA.

The reliability logic diagrams constructed for the model to simulate the Apollo-Saturn 504 Mission included representations of 957 hardware elements. These elements varied in complexity from a launch vehicle stage, to an accelerometer in a subsystem. Many of these 957 representations required delineation of thousands of impinging considerations. A logic diagram reduces these intermingled complexities to manageable configurations.

C.1.4.5 <u>Reliability Data</u>

Reliability data are used to compute success probabilities for given equipment over specified intervals in the mission. Such data include:

1. Failures with respect to either time or cycles of operation.
2. Failure modes.

3. Environmental stress modification factors.
4. Operating mode stress modification factors.
5. Equipment Operating Profile.

C.1.4.6 Equipment Operating Profiles

Reliability analyses require equipment operating profiles that provide a subphase by subphase description of the performance requirements for all equipment that will operate during the mission. These profiles take into account such factors as: the duration of time equipment must function; its status during each point in mission, i.e., "on", "off", "standby", etc., mode of operation and environmental stress factors.

Information for the equipment operating profiles is extracted from Center/contractor documents, supplemented by the Design Reference Mission document (Reference 2). Failure rate data is also extracted from accepted failure rate data sources. The importance of monitoring reliability data supplied by contractors and their vendors is illustrated by an instance in which the failure rate listed for a pressure transducer was almost 1/2000th of the failure rate listed in accepted failure rate sources (Reference 62).

C.1.5 APPLICATION OF RELIABILITY ESTIMATION

C.1.5.1 Apollo-Saturn 504 Mission

The body of this Appendix gives present reliability estimates for the Apollo-Saturn 504 Mission as related to crew safety and mission success. The estimates are given as probabilities derived from reliability analyses of apportionment, prediction, mission and system information as they relate to the Saturn V Launch Vehicle, the Apollo Spacecraft, stages, modules and subsystems. Information on the Ground Operational Support System and the Manned Space Flight Network is included in summarized form. Pre-liftoff aspects are not included in the current analysis.

C.1.5.2 Apollo-Saturn 201 Mission

The model for this mission contains many of the same or similar elements described in this Appendix. There are differences in the way the models are structured, reflecting the specific system/mission design and reliability analysis needs of each mission;

but the similarities are such that much of the Apollo-Saturn 504 Mission/system information, logic diagrams, and reliability data has direct application to the Apollo-Saturn 201 Mission, which is detailed in the Quarterly Report, Section I.

* * *

The estimates of the probabilities of crew safety and mission success reported in this Appendix are made periodically and provide a means for comparing program progress with declared program goals. The estimates also provide definite answers to such questions as, "How far is the program from its mission success goal?", "Which is the most dangerous part of the mission and why?" Such information can lead to conclusions and remedial action by program management which will help insure attainment of program objectives and announced goals.

[redacted]

C.2 SUMMARY

This section presents the major results of the reliability analysis of the Apollo-Saturn 504 Manned Lunar Landing Mission. Additional information amplifying and supplementing the results are provided in subsequent sections.

The current reliability status of the Apollo-Saturn 504 mission and systems is expressed in terms of system and mission phase impact on the chances of crew safety and mission success, on associated technical problems, documented reliability apportionments, reliability predictions, and crew safety and mission success probability degradation as a function of mission time and phase.

Apollo Program documentation, including documents issued by the Manned Space Flight Center, Marshall Space Flight Center, and their respective contractors, provides basic information for this mission analysis. Center/contractor reliability prediction and apportionment data together with reliability models and other engineering information were used to structure the Apollo-Saturn 504 Manned Lunar Landing mission/system simulation model, providing the Apollo Program Office estimates of:

- Predicted system/equipment reliability
- Predicted mission phase reliability
- Predicted crew safety probability
- Predicted mission success probability

In addition, the unreliability contributions by equipment, system, stage/module and mission phase were derived from the mission simulation. Tabulations providing comparisons of contractor documented reliability apportionments and predictions are included in this Appendix. Ground Operational Support System reliability considerations are given in summarized form. Prelaunch aspects are not included in this analysis.

C.2.1 SATURN V LAUNCH VEHICLE

The Saturn V Launch Vehicle is comprised of the S-IC, S-II, S-IVB and Instrument Unit. The Saturn V Launch Vehicle reliability prediction of 0.76 approaches the apportionment of 0.85 stated in the Saturn V Program Development Plan (Reference 10). There is no significant difference between Apollo Program Office and Center/contractor predictions of mission success for the Saturn V Launch Vehicle.

[redacted]

The S-II and the S-IVB are the largest contributors (approximately 42 percent and 35 percent respectively*) to the total Launch Vehicle unreliability of 40 percent. Figure C.4-1 shows relative contributions of each Stage to the predicted Launch Vehicle unreliability.

Figure C.4-2 shows the predicted Launch Vehicle and Stage success probabilities as a function of mission phase.

The J-2 engines (S-II and S-IVB Stages) are the greatest contributors to Launch Vehicle unreliability, primarily because of the relatively long operating time of the five engine subsystems during the mission and because of J-2 malfunction problems. There are other equipments which stand out significantly as main contributors to the Launch Vehicle unreliability. These equipments are: the duct gimbal joints and ducting bellows (S-IC Stage), the auxiliary propulsion engines (S-IVB Stage), and an equipment selector switch in the S-IVB Stage.

The S-IC Stage and the Instrument Unit combined contribute approximately 23 percent to the unreliability of the Launch Vehicle. The stage-by-stage comparison of reliability apportionments and predictions shows no appreciable difference between Center/contractor and Apollo Program Office values.

C.2.2 APOLLO SPACECRAFT

The Apollo Spacecraft is comprised of the Command Module, Service Module, and Lunar Excursion Module.

Technological interfaces have given rise to the term "Command Service Module", acknowledging the fact that two modules function essentially as one unit during the entire mission (up to the nominal mission event, "Service Module Jettison", at about 198 hours after liftoff). Launch Escape System and Adapter are included with those considerations concerning the Command Service and Lunar Excursion Modules respectively.

(*) Percentages have been rounded off.

Analysis results show that approximately sixty percent of the mission unreliability of the Apollo Space Vehicle is due to the Spacecraft. With this percentage taken as a base, the Command Service Module contributes 69 percent and the Lunar Excursion Module contributes 31 percent to Spacecraft unreliability. Of all Spacecraft systems and Launch Vehicle Stages, the Command Service Module Guidance, Navigation and Control system ranks first, with a percentage contribution to predicted overall mission unreliability of 17.6 percent. Figure C.5-5 illustrates mission success probability versus major mission phases.

Values for the probability of crew safety cited in Center/contractor documents relate separately to the Command Service Module and the Lunar Excursion Module. The Apollo Program Office believes that the computation of crew safety probability for the manned lunar landing mission must be based upon considerations of all participating systems including Ground Operational Support (See also Reference 4). This belief, however, does not deny the necessity on the part of the Manned Space Center and its contractors to explicitly consider and include in program documentation their estimates of the probability of crew safety for both the Command Service and Lunar Excursion Module. For the reasons just given the Apollo Program Office has focused attention on estimates of the probability of Spacecraft systems success where these estimates are based upon Center/contractor predictions for successful operation of Spacecraft systems during a manned lunar landing mission.

The Apollo Program Specification (Reference 1) cites the Command Service and Lunar Excursion Module reliability apportionments (mission success goals) as 0.96 and 0.98 respectively. These figures are in agreement with the Center/contractor documented reliability apportionments (References 52 and 42). The corresponding Center/contractor apportionment values(*) are 0.964 and 0.987. The product of these two numbers is 0.96.

The Apollo Program Office predictions, based on Center/contractor subsystem and component reliability predictions for the Command Service and Lunar Excursion Module, are 0.766 and 0.889, respectively. The product of these two numbers is 0.68.

(*) Numbers are rounded off.

The Center/contractor predictions for the Command Service and Lunar Excursion Module are 0.944 and 0.844, resulting in a product of about 0.83. The relatively large difference between the Center/contractor and Apollo Program Office predictions for the Command Service Module and, therefore, the Apollo Spacecraft, is due to currently unresolved differences between Center/contractor and Apollo Program Office reliability models, data, and mission information. In particular, the Apollo Program Office considers some of the abort criteria, backup modes, and redundancies to be questionable. For example, the contractor's reliability logic diagrams of the CSM Environmental Control System incorporated the assumption that the mission will be aborted only after failure of the <u>secondary</u> suit loop compressor. The present analysis assumes that the mission will be aborted after the <u>primary</u> suit loop compressor fails.

The Manned Spacecraft Center is currently working with the contractors to resolve this and similar problems concerning other spacecraft systems and subsystems.

C.2.2.1 <u>Command Service Module (CSM)</u>

The Command Service Module contributes 41 percent to mission unreliability. Figure C.5-5 shows the percentage contribution of systems to this Command Service Module unreliability.

A summary discussion of the reliability status of the Command Service Module subsystems follows.

C.2.2.1.1 CSM Guidance, Navigation and Control System

This system contributes 42.8 percent to the Command Service Module unreliability. Ground rules (Reference 32) dictate that the mission be aborted if any of the Guidance Navigation equipments fail prior to initiation of Lunar Excursion Module descent. This ground rule plus the unreliability of the two continuously operating Flight Director Attitude Indicators, and the two Gyro Packages, make the Guidance, Navigation and Control system of the Command Service Module the leading contributor to the probability of mission failure. Continuous operation of both Indicators and Gyro Packages during the long Translunar Coast phase significantly degrades reliability. Placing the equipment in the "off" or "standby" mode during most of the translunar coast phase of the mission should be considered. A comparison of the present prediction estimate to the contractor's apportionment and prediction values cannot be made at this time because the contractor does not consider the Guidance, Navigation and Control system as a separate system but as part of the Integrated Electronics system. The Apollo Program Office prediction estimate of 0.984 reflects the Guidance, Navigation and Control system as a separate portion of the module.

C.2.2.1.2 CSM Environmental Control System

The Environmental Control system contributes 19.8 percent of the predicted Command Service Module unreliability. Most of the system unreliability is due to leakage around the pump bearings in the water glycol circuit. Improvements in the design are being evaluated.

C.2.2.1.3 CSM Communications System

The Communications system contributes 11.8 percent of the predicted Command Service Module unreliability.

Communications during the translunar coast may be unreliable due to expected performance limitations on the S-band directional antenna and the S-band power amplifier. In the absence of contractor information, definitive ground rules for determining mission success were postulated for analysis purposes. The current prediction is conservative because the possibility of successfully completing a mission with degraded communications has not been considered.

Contractor apportioned and predicted mission success reliabilities are grouped under the general title of Integrated Electronics; therefore, no valid comparison with the Apollo Program Office prediction is possible.

C.2.2.1.4 Service Propulsion System

This system contributes 11 percent to the predicted Command Service Module unreliability. Combustion instabilities and the long operating time of the propellant tanks degrade the reliability of the system. The storage tanks, in use for the entire mission, are the largest contributors to mission unreliability in this system.

C.2.2.1.5 Service Module Reaction Control System

The Reaction Control System contributes 5.67 percent to the predicted Command Service Module unreliability. The propellant tank bladders exhibit high diffusion characteristics and are considered low reliability equipments because of the resultant degradation in propellant flow and the threat of propellant explosion.

C.2.2.1.6 CSM Electrical Power System

The Electrical Power System contributes 7.1 percent to the predicted Command Service Module unreliability. The universal inverter (inverter No. 3) contributes most to mission unreliability in this system. While continuous operation is required for most components of the Command Service Module Electrical Power system, this is not true for the static inverters. The normal operating mode for the inverters requires that inverters No. 1 and No. 2 operate during the boost phases of launch and during each ΔV maneuver. Only inverter No. 1 operates at all other times. Should inverter No. 1 fail, inverter No. 2 begins continuous operation. Should inverter No. 2 also fail, the mission is aborted and inverter No. 3 is used. Although only one inverter operates throughout the majority of the mission, the non-operating inverters are also subject to failure.

The following Block II Design will affect the reliability estimates:

(1) Expected elimination of the pyrotechnic separation batteries.

(2) Redesign of the present high acoustical noise static inverters, used in Block I, to obtain a low noise Block II static inverter. This redesign is expected to cause a different failure probability for the static inverters due to addition of components.

(3) Replacement of the 25-ampere hour Entry and Post-Landing Batteries by 40-ampere hour batteries. This change is expected to lessen the criticality of the battery charger.

C.2.2.1.7 CSM Miscellaneous Systems

The Command Service Module Structures, Emergency Detection System, Launch Escape System, Earth Landing System, Heat Shield, and Separation System contribute 0.9 percent in total to the module unreliability. Only fixed point reliability values were available for each of these systems. There are no differences between the Center/contractor and the Apollo Program Office reliability predictions.

C.2.2.1.8 Command Module Reaction Control System

The Command Module Reaction Control System contributes 0.6 percent to the predicted total module unreliability. The helium tanks which are pressurized for the entire mission, are the heaviest contributors to the probability of system failure. Since the propellant tanks are not pressurized until just prior to re-entry, expulsion bladders do not appear to present a reliability problem.

C.2.2.1.9 CSM Cryogenic Storage System

The Cryogenic Storage System contributes 0.3 percent to the predicted Command Service Module unreliability. The equipment needed for quantity gauging is the most unreliable part of the Cryogenic Storage System. Specifically, the pressure transducer and quantity probe and indicator are critical items.

C.2.2.2 Lunar Excursion Module (LEM)

The Center, contractor, and Apollo Program Office mission success reliability predictions for the Lunar Excursion Module are in agreement. The Lunar Excursion Module contributes 18.5 percent to the predicted mission unreliability. The percentage contribution of systems to Lunar Excursion Module unreliability is shown in Figure C.5-9.

C.2.2.2.1 LEM Electrical Power System

The Electrical Power System contributes 37 percent of the predicted Lunar Excursion Module unreliability. This is due to the operational ground rule requiring all four descent batteries to operate during the lunar stay period. The duration of this period (approximately 35 hours), combined with the battery failure rate, accounts for 70% of the Electrical Power System unreliability. A lunar stay of only 20 hours, for example, would increase the probability of mission success because only three of the four descent batteries would be required.

C.2.2.2.2 LEM Communications System

The Communications System contributes 22 percent to the predicted module unreliability. The Extra Vehicular Activity (EVA) backpack transceiver contributes most to the probability of system failure because of a high failure rate and mission use time. The high failure rate, however, is questionable since each transceiver has two transmitters and two receivers. Therefore, the total failure of one backpack receiver does not necessitate an abort of the mission but merely degrades the efficiency of the lunar exploration.

C.2.2.2.3 LEM Environmental Control System

The Environmental Control System contributes 16.6 percent of the predicted total module unreliability. The major Environmental Control System problems are in the water-glycol circuit, the pressure suit compressor and in the cabin recirculating blower. All three subsystems have low reliability brushless DC motors.

C.2.2.2.4 LEM Guidance and Control System

The Guidance and Control System contributes 11 percent of the predicted total module unreliability. The abort sensor assembly contains all the inertial reference equipment and is the most unreliable component in the system.

C.2.2.2.5 LEM Reaction Control System

The Reaction Control System contributes 10.7 percent of the predicted total module unreliability. The propellant bladders are the most unreliable components.

C.2.2.2.6 LEM Miscellaneous Systems

The Miscellaneous Systems contributed 2.6 percent of the predicted total Lunar Excursion Module unreliability. The Miscellaneous Systems include the Lunar Excursion Module Structures, Ascent and Descent Propulsion, and Pyrotechnics System. Reliability information on these systems was limited at the time of this analysis. Fixed value reliability estimates from the Apollo Program Office data bank compare well with the contractor apportionments and predictions.

The major problem in the Ascent and Descent Propulsion Systems is the re-seating of the valves after an operational cycle. Purge and filtering techniques are being improved to alleviate this problem.

C.2.2.2.7 Crew Systems

The current configurations of the crew system were discussed at a recent Manned Space Flight Center Reliability Data Review Meeting. It was tentatively agreed that the Crew System and Crew Provisions should first be studied from a Failure Mode Effect Analysis and Configuration viewpoint before presenting the Crew System elements in reliability logic diagrams. A reliability of 1.0 was assumed for the crew system and crew performance in this analysis.

C.2.3 GROUND OPERATIONAL SUPPORT SYSTEM (GOSS)

The Apollo Saturn Ground Operational Support System (GOSS), composed of the Manned Space Flight Networks (MSFN) and the Control Centers, is an information transportation system supporting the communications and tracking capabilities of the Space Vehicle. GOSS is composed of complex facilities which will be operated by many and diversified agencies. These facilities will be variably configured for each mission.

In general, the Launch Vehicle support requirements from the MSFN include telemetry, tracking, and digital command communications for 6.5 hours following liftoff (lunar landing mission). The Command Service Module requirements include voice communications, telemetry, tracking, and digital command communications throughout the entire mission except during periods of thrusting. Television is specified during earth orbit and translunar coast phases. Voice communications, telemetry, and tracking are required during operation of the Lunar Excursion Module, and television is included during lunar surface operations.

GOSS support to the mission during earth orbit is limited to about one-third of the time. This limitation is due to the GOSS station location and antenna coverage with relation to the space vehicle ground track. Launches at higher than 72° azimuth, whether planned or resulting from launch delay, could result in less coverage. Mission events obscured by the moon cannot be directly supported by GOSS.

Current recommended mission ground rules require mission abort when one more failure would result in loss of the crew. The Block II Guidance, Navigation and Control System to be used in all manned lunar flights, and included in the present analysis, will depend on earth-based tracking. The on-board capability is retained, but only as a back-up. Since there are but two means of navigation, loss of either dictates an abort.

Currently, neither Center nor contractor documents indicate that apportionments and predictions include reliability aspects of associated ground based equipment.

C.2.4 CREW SAFETY AND MISSION SUCCESS

C.2.4.1 <u>Mission and System Analysis</u>

This analysis related probabilistic measures of mission/system effectiveness to the fifteen major phases of the Design Reference Mission and to Apollo Saturn V Space Vehicle systems making the largest contribution to mission unreliability.

The Launch Vehicle and Spacecraft contribute about 40 percent and 60 percent, respectively, to total unreliability for the Apollo-Saturn 504 Mission. (Mission unreliability equals one minus the probability of mission success). The operational mission time of the Launch Vehicle, however, is only about three (3) hours compared to 198 hours for the Spacecraft. Thus, the unreliability contributions are 13.5 and 0.3 percent per mission hour for the Launch Vehicle and Spacecraft, respectively.

Figure C.2-1 shows the ranking of the fifteen mission phases by contribution to mission unreliability, and indicates which system accounts for the largest share of the unreliability within that phase. Also ranked are the contributions of the phases to possible crew loss. The Transearth Coast phase ranks highest in probability of crew loss. This phase spans a longer time period (88 hours) than any other phase. In this portion of the mission there is no alternate route to the landing area and, approximately after first midcourse correction thrusting in this phase, neither primary nor secondary mission abort capability exists. Consequently, mission failure in this phase is synonymous with crew loss. This condition is reflected in the high safety hazard ranking.

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

Mission Phase	Leading System Contributor to Mission Unreliability	Rank by Phase Contribution to Mission Unreliability	Rank by Relative Safety Hazard
Earth Ascent	S-II Stage	2	12
Earth Orbit	S-IVB Stage	3	11
Translunar Injection	S-IVB Stage	13	14
Initial Translunar Coast	S-IVB Stage	6	13
S-IVB Jettison to Lunar Orbit Insertion	CSM(1) Guidance, Navigation and Control	1	2
Lunar Orbit Insertion	Service Propulsion	12	7
Lunar Orbit Coast to LEM Separation	LEM(2) Electrical Power	5	10
CSM Solo/LEM Separation and Descent	LEM Reaction Control	7	4
Hover to Touchdown and Lunar Stay	LEM Electrical Power	4	3
Lunar Excursion Module Ascent	LEM Guidance and Navigation	10	6
Lunar Orbit Coast to Transearth Injection	CSM Environmental Control	9	9
Transearth Injection	CSM Guidance, Navigation and Control	11	5
Transearth Coast	CSM Environmental Control	8	1
Entry	CM(3) Reaction Control	15	12
Parachute Descent	CSM Miscellaneous Systems	14	8

(1) Command Service Module

(2) Lunar Excursion Module

(3) Command Module

Figure C.2-1. Mission Phase and System Criticality Rankings

The S-IVB Jettison to Lunar Orbit Insertion phase is the prime contributor to mission unreliability. This phase also ranks high (second) in relative safety hazard due to abort criteria and abort duration. Abort criteria for the Command Module Guidance and Navigation System require that the mission be aborted if any of the Guidance and Navigation system equipments fail. Once initiated, abort from this phase extends over a long flight path and a successful abort requires continued use of the system whose partial failure caused the abort.

The general assumptions applied to the equipments and functions in the formulation of the Apollo-Saturn 504 Mission simulation model are listed below:

1. At the instant of liftoff, all space vehicle systems and their equipments are operating properly.
2. Nominal flight trajectories, and nominal environmental conditions both external and internal to the space vehicle prevail and nominal system performance levels are attained by non-failed systems and equipments throughout the mission.
3. Systems, equipments, or functions for which reliability data were either unavailable or inapplicable, were assigned a reliability of 1.0. This assigned value was applied to the following items:
   a. Flight crew functions
   b. Ground Operational Support System
   c. Oxygen Supply (Descent), Lunar Excursion Module Environmental Control
   d. LiOH Cartridge, Lunar Excursion Module Environmental Control
   e. Portable Life Support System Cartridge, Lunar Excursion Module Environmental Control
   f. Ground Support Equipment Disconnect, Lunar Excursion Module Environmental Control
   g. Line of Sight/Velocity Indicator, Lunar Excursion Module Guidance, and Control
   h. LiOH Canister Check Valve, Command Service Module Environmental Control
   i. Backup Roll Attitude Display, Command Service Module Guidance, Navigation, and Control

j. Entry Monitor Display, Command Service Module. Guidance, Navigation and Control

C.2.5 RELIABILITY APPORTIONMENT AND PREDICTION ESTIMATES

Differences between the reliability apportionments and the reliability predictions for Launch Vehicle Stages and Spacecraft Modules are ranked below in order of decreasing magnitude:

System	Difference (*)
Lunar Excursion Module	+.103
S-II Stage	+.057
S-IVB Stage	+.040
S-IC	-.026
Instrument Unit	+.024
Command Service Module and Adapter	+.020
Ground Operational Support	Unknown

In this Appendix reliability apportionment and prediction values at the overall mission and stage/module level are tabulated in Sections C-3, C-4 and C-5.

Based upon Center/contractor reliability apportionments, the estimates of mission success and crew safety probabilities are 0.96 and 0.73, respectively, as reported in the previous Quarterly report dated 9 July 1965 (Reference 4).

Apollo Program Office estimates of crew safety and mission success probabilities, based on current Center/contractor reliability predictions, are shown in Figure C.3-3 as a function of mission time. The major causes of the degradation of probability values and the names of the mission phases are noted in this figure. The Apollo Program Office predictions of crew safety and mission success probabilities for the manned lunar landing mission are 0.96 and 0.52, respectively.

(*) Rounded to three decimal places.

C.3 APOLLO-SATURN 504 CREW SAFETY AND MISSION SUCCESS ANALYSIS

Treated in this section are those aspects of the reliability status best reviewed in the context of the overall Apollo-Saturn 504 Mission and system. The current estimates of the probabilities of crew safety and mission success, based on both reliability apportionments and predictions, are compared in this section with declared program goals. The causes of reliability degradation in mission phases and flight hardware are identified along with the space vehicle criticality estimates and mission characteristics or ground rules which give rise to existing reliability problems.

C.3.1 CREW SAFETY AND MISSION SUCCESS PROBABILITY ESTIMATES

C.3.1.1 Reliability Apportionment

The reliability simulation performed for the Apollo-Saturn 504 Mission using Center/contractor reliability apportionment values previously reported in "Apollo Reliability and Quality Assurance Program Quarterly Progress Report (U)" (Reference 4) dated 9 July 1965, provided estimates of 0.73 for mission success and 0.96 for crew safety. These are still the current estimates, being essentially unchanged since that report. (Figure C.3-1)

C.3.1.2 Reliability Predictions

The estimated probabilities are 0.52 for mission success and 0.96 for crew safety based on Center/contractor reliability predictions. A comparison of these probabilities with the stated reliability goals shows that reliability improvement is required to meet announced goals. Comparison between contractor apportionments and predictions, for each stage and module, is given in Figure C.3-2.

Estimated crew safety and mission success probabilities decrease as a function of mission time (Figure C.3-3). All systems are assumed to be functioning as intended at the instant of "liftoff", which is the zero point on the mission time line. The names of major mission phases are shown in Figure C.3-3 at the time points corresponding to the end of each mission phase. The causes for reliability degradation during the major mission phases are detailed in Section C.3-2.

CONFIDENTIAL

System	Apollo Program Specification	Ref.	Contract Work Statement	Ref.	Program Plan	Ref.	Contractor Published	Ref.	Apollo Program Office
S-IC Stage	.95	1			.95	10	.95	9	.9071*
S-II Stage	.95	1			.95	10	.95	11	.9155
S-IVB Stage	.95	1	.95	24	.95	10	.95	18	.9414
Instrument Unit	.99	1			.992	10	.992	10	.992
Command Service Module and Adapter	.96	1			.9638	30	.9638	38	.9638
Lunar Excursion Module	.98	1			.984	66	.987	42	.987
Ground Support									
Overall Apollo Saturn Mission Success Probability									.73
Overall Apollo Saturn Crew Safety Probability									.96

*Contractual reliability goals for engines used in calculation for stage reliability.

Figure C.3-1. Reliability Apportionment Values

[redacted]

~~CONFIDENTIAL~~

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Contractor Published	Ref.	Difference Apportionment Prediction	Apollo Program Office Prediction Estimates
S-IC Stage	.9757	5	-.0257	.9757
S-II Stage	.893	14	+.057	.893
S-IVB Stage	.910	18	+.040	.910
Instrument Unit	.968	22	+.024	.968
Command Service Module	.944032	38	+.019818	.7662
Lunar Excursion Module	.8840	42	+.10300	.88942
Ground Operational Support				
Overall Apollo Saturn Mission Success Probability			+.18	.52
Overall Apollo Saturn Crew Safety Probability			0	.96

Figure C.3-2. Stage/Module Reliability Predictions and Prediction Versus Apportionment Comparisons

[redacted]

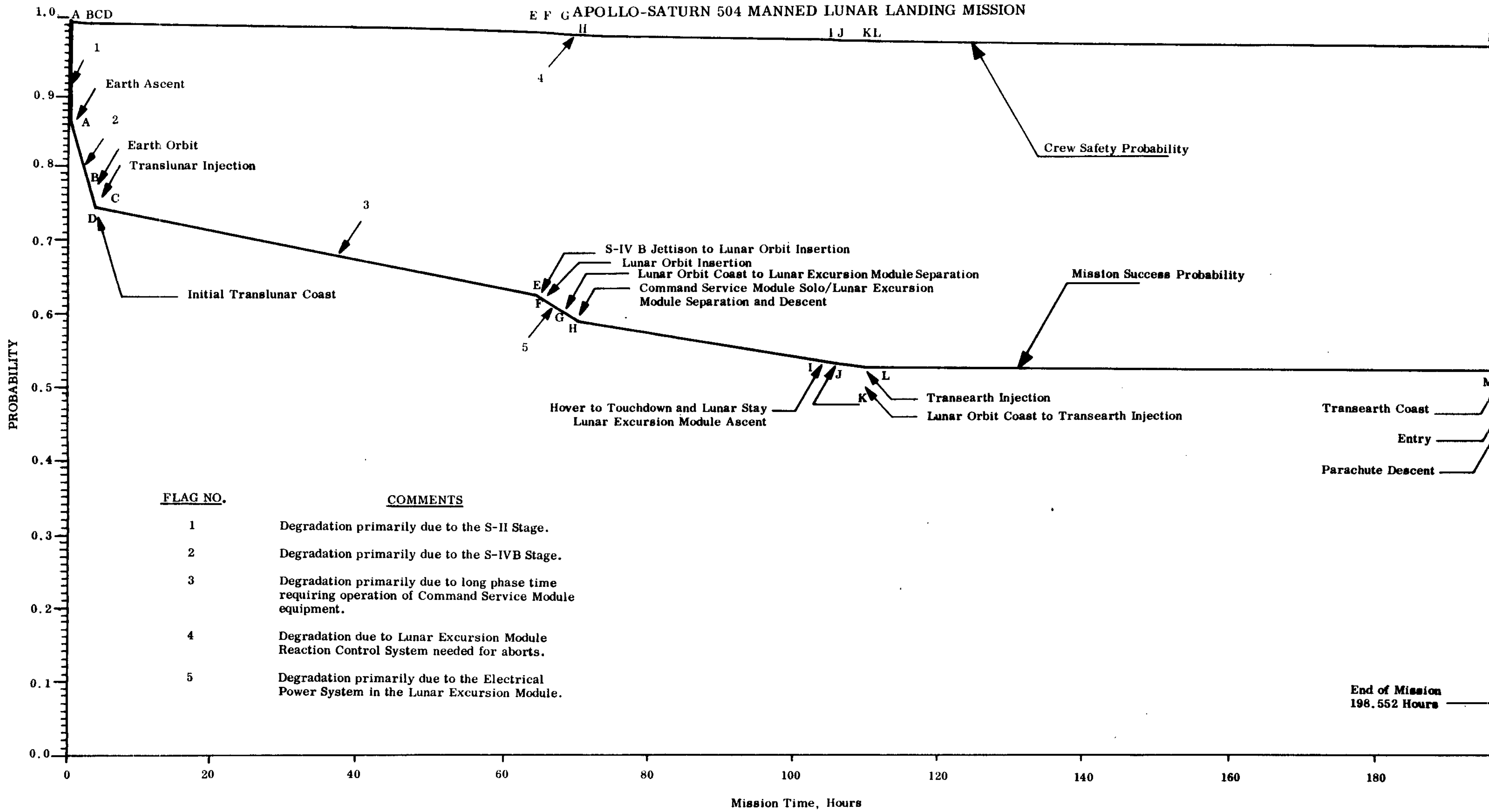


Figure C.3-3. Mission Success and Safety Probabilities Versus Time

C.3.2 MISSION PHASE CRITICALITY ESTIMATES

Two measures are used to identify the criticality of mission phases. The first measure, "relative safety hazard", compares the chance of crew loss in one phase of the mission to this risk in another phase (Figure C.3-5). The term "risk" here applies to the probable loss of the space vehicle crew either at a point on the nominal mission or during an abort. The second measure, "percentage contribution to mission unreliability", provides a quantitative measure of the comparative criticality of a mission phase with respect to overall mission success (Figure C.3-4). Both measures are derived from results obtained from the mission reliability analysis based upon Center/contractor predictions.

The S-IVB Jettison to Lunar Orbit Insertion phase is estimated to be the prime contributor to mission unreliability. This ranking is due to the relatively long (64.3 hours) phase time and the abort criteria which require mission abort prior to serious system failure. One abort criterion for the Command Module Guidance and Navigation System (the leading contributor to the probability of mission failure in this phase) is that the failure of any one of the components in this system results in a mission failure. Figure C.3-5 shows this phase to be second in terms of relative loss of crew safety, due to the relatively high probability of abort initiation during this phase and the long abort paths that require guidance and navigation from the same systems which caused abort initiation.

The Earth Ascent phase ranks second in terms of contribution to mission unreliability. The S-II stage is the leading contributor to the probability of mission failure during this phase. There is a high probability of safe crew return in the event of abort during this phase, because the abort paths are short. Therefore, this phase ranks very low with respect to danger to the crew.

The Earth Orbit phase is the third ranking contributor to mission unreliability. In this phase unreliabilities in the S-IVB stage make it a major contributor to the probability of abort initiation. This phase however, ranks low in contribution to the probability of crew loss because of safe return possibilities.

The Hover to Touchdown and Lunar Stay phase ranks fourth in contribution to mission unreliability. The long phase time combined with the intricate landing maneuver result in a comparatively high probability of mission failure. The Lunar Excursion Module Electrical Power System is the leading contributor to phase unreliability. This phase is the third leading contributor to the probability of crew loss (See Figure C.3-5).

The Lunar Orbit Coast to Lunar Excursion Module Separation phase is the fifth ranking contributor to mission unreliability. The LEM Electrical Power System is the prime contributor to the probability of abort initiation. With respect to the relative safety hazard, Figure C.3-5 shows this phase ranks seventh. The low probability of mission failure due to LEM Systems (not needed on the aborts), is a major factor in the low ranking.

It should be noted that the mission model was structured with an assumption that a failure of a LEM equipment prior to crew boarding would be undetected. Since many of these equipments are "on" from liftoff, the probability of mission abort in the period immediately after the preliminary system checkout is rather high.

The Initial Translunar Coast phase ranks sixth in contribution to mission unreliability. The S-IVB stage is the leading contributor to the probability of mission failure. The subsystems in the S-IVB which contribute most to stage unreliability have time dependent failure characteristics and these subsystems must operate during this comparatively long phase. This phase ranks low in contribution to the probability of crew loss because of the high probability that an S-IVB stage failure initiating an abort will leave the abort essential systems in a functioning condition; also, the abort time is relatively short.

The CSM Solo/Lunar Excursion Module Separation and Descent phase is the seventh ranking contributor to mission unreliability. In this phase, LEM systems are the leading contributor to mission failure probability. Strict abort criteria applied to these systems in this phase, combined with exacting mission/system functional requirements, also account for this rank. The LEM Reaction Control System is the prime contributor (47 percent) to mission unreliability. Since the Reaction Control System is also required for abort, this phase ranks high (fourth) in relative safety hazard.

The Transearth Coast phase ranks eighth in contribution to mission unreliability. This phase spans a longer time period (88 hours) than other major phases. The CSM Guidance and Navigation system is the leading contributor to the probability of mission failure. This phase ranks first in contribution to the probability of crew loss because successful aborts are not possible during this time period. In this portion of the mission there is no alternate route to the landing area and, approximately after first midcourse correction thrusting in this phase, neither primary nor secondary mission abort capability exists. Consequently, mission failure in this phase is synonymous with crew loss. This condition is reflected in the high safety hazard rank. The relative safety hazard of <u>all</u> in-flight phases is shown in Figure C.3-5, and the contributions of all phases to mission unreliability are shown in Figure C.3-4.

C.3.3 SPACE VEHICLE RELIABILITY

The launch vehicle stages (in total) contribute approximately 40 percent of the mission unreliability, compared to a contribution of approximately 60 percent unreliability by the spacecraft modules. The operational mission time of the Launch Vehicle, however, is approximately three hours, compared to 198 hours for the Spacecraft. Thus, the unreliability contributions are approximately 13.5 and 0.3 percentage points per mission hour for the Launch Vehicle and Spacecraft respectively. The percentage contribution of each stage and module to mission unreliability is shown in Figure C.3-6.

The relative criticality of launch vehicle stages and spacecraft subsystems in the execution of the mission is shown in Figure C.3-7. Explanation for these rankings is given in Sections C.4 and C.5. The rankings of other phases are given in Figure C.3-5.

C.3.4 SUBSYSTEM RELIABILITY

The leading subsystem contributors to mission unreliability are listed in Figure C.3-8. Technical discussion concerning these equipments are in Section C.4 and C.5 where the Launch Vehicle and Spacecraft reliability analysis and status are presented.

CONFIDENTIAL

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

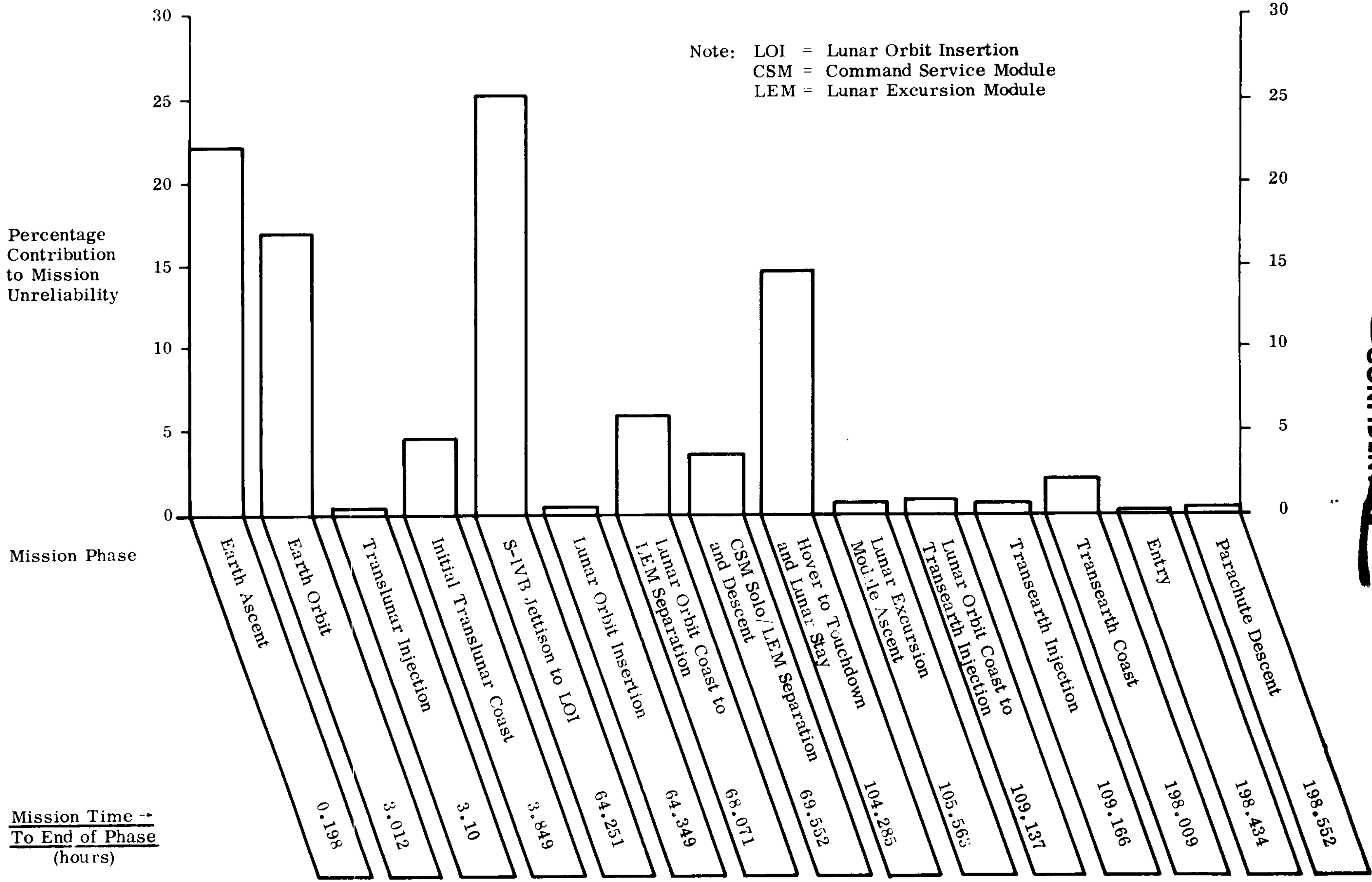


Figure C. 3-4. Percentage Contribution to Mission Unreliability versus Mission Phase

[redacted]

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

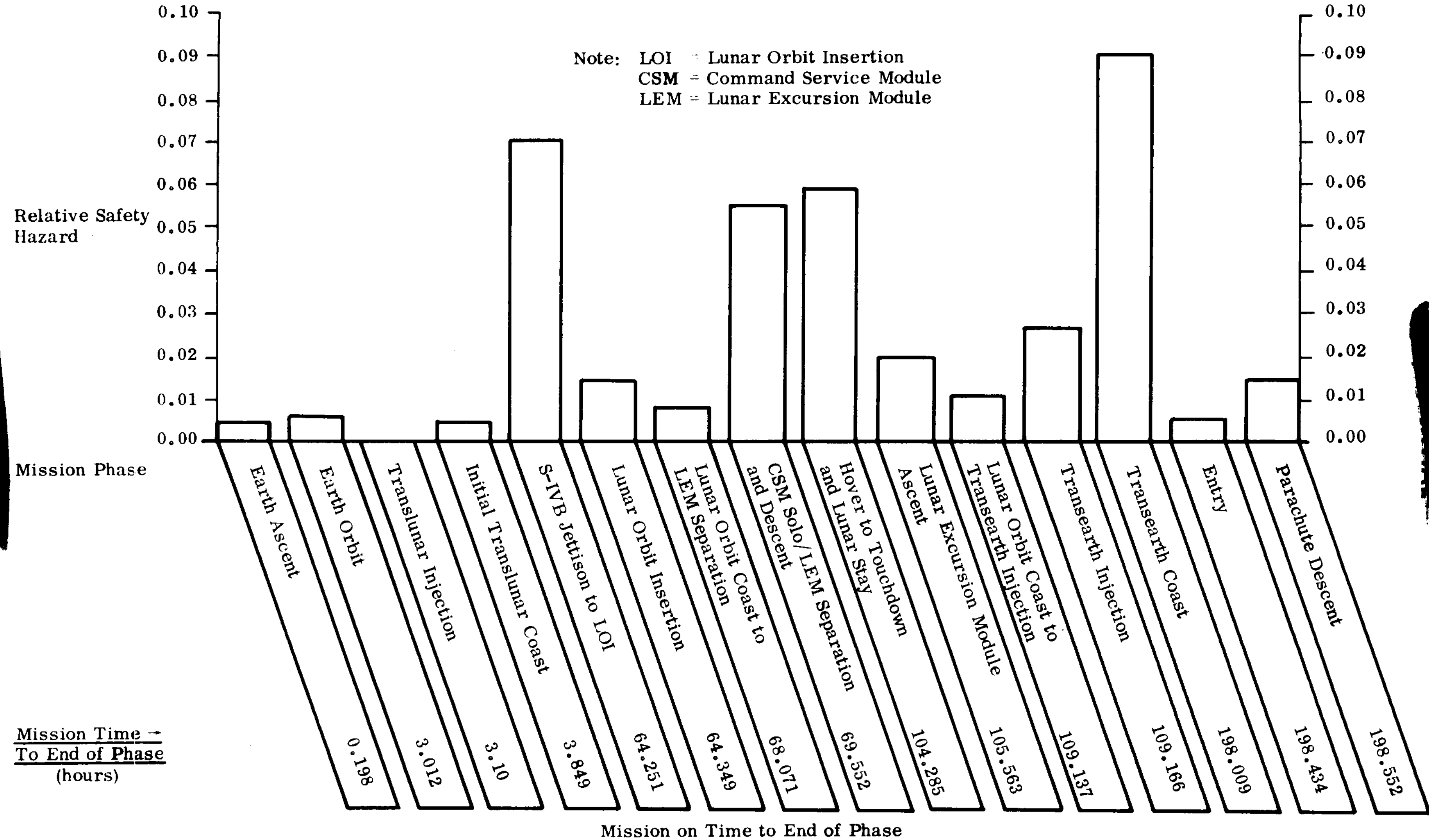


Figure C. 3-5. Relative Safety Hazard versus Mission Phase

[redacted]

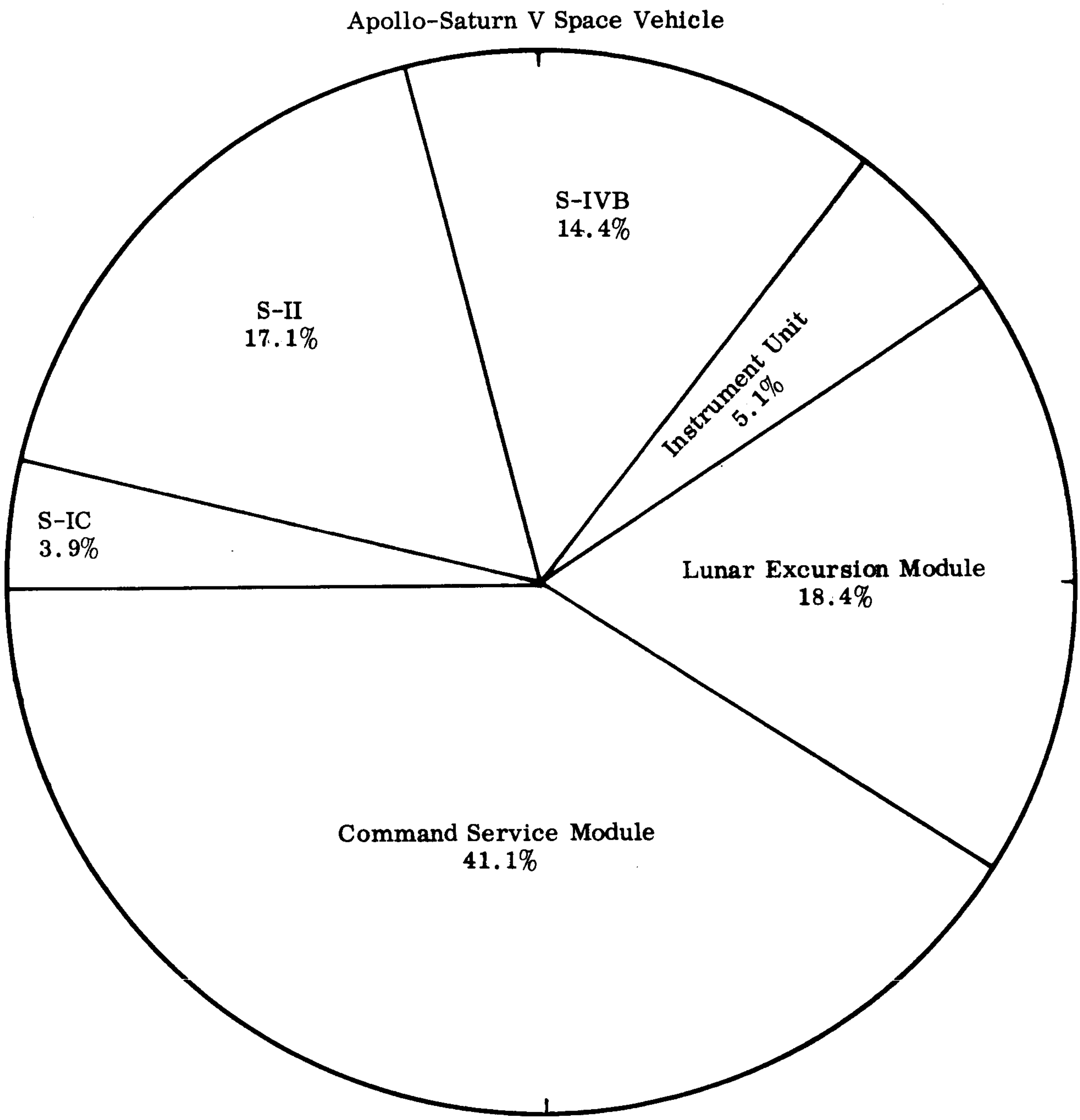


Figure C.3-6. Percentage Contribution of Stages and Modules to Space Vehicle Mission Unreliability

[redacted]

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

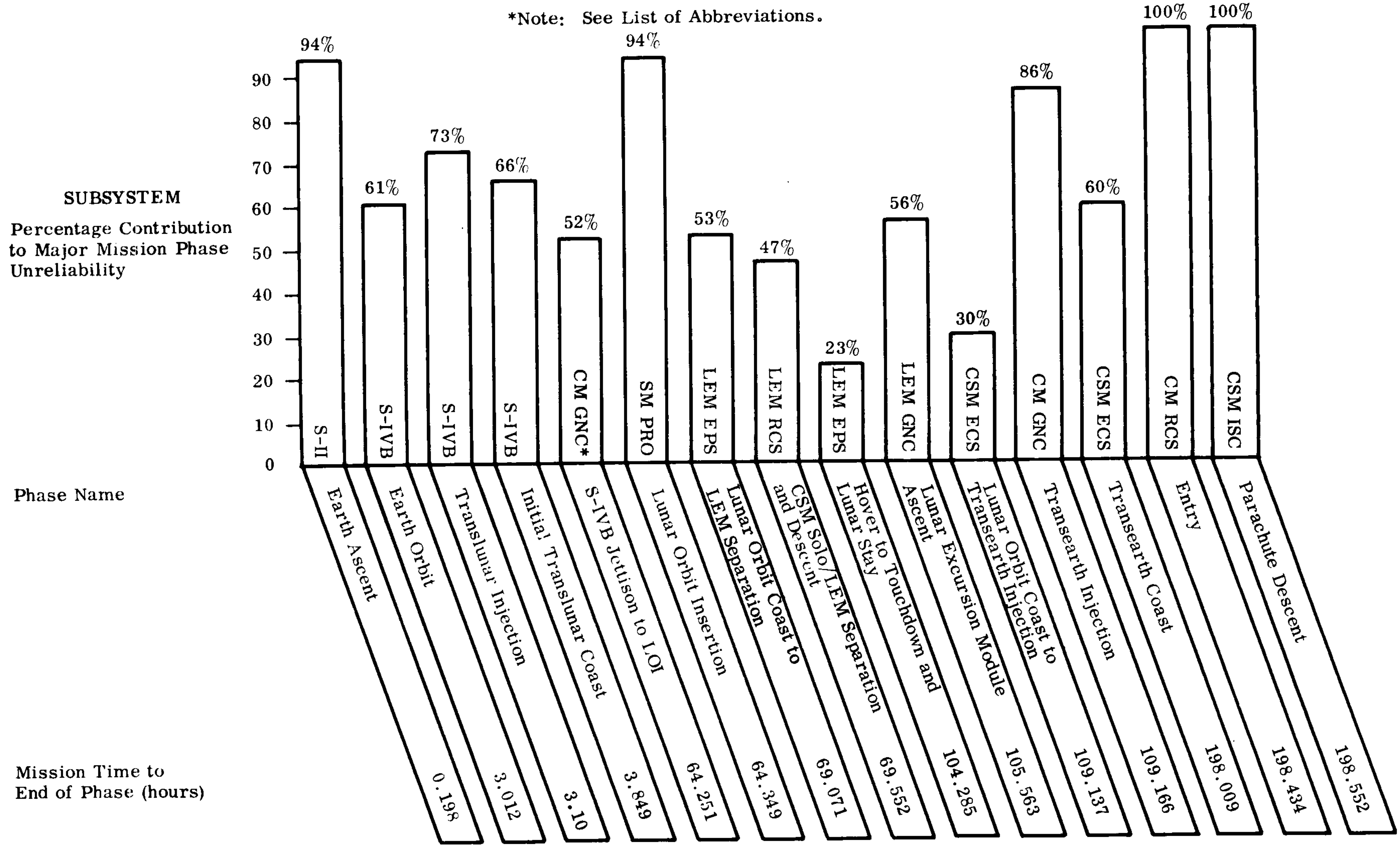


Figure C. 3-7. Major Contributors and Percentage Contributions to Mission Unreliability versus Mission Phase

[redacted]

Stage/Module*	System	Percentage	Rank
CM	Guidance, Navigation and Control	17.61	1
CSM	Environmental Control System	8.12	2
LEM	EPS Battery	6.83	3
S-IVB	Electrical	6.35	4
	Instrument Unit	5.11	5
S-II	J-2 Engines	4.95	6
CSM	Communications	4.86	7
SM	Propulsion	4.51	8
LEM	Communications	4.06	9
S-IVB	Flight Control	3.23	10
LEM	Environmental Control System	3.07	11
CSM	Electrical Power System	2.92	12
S-II	Electrical Control	2.40	13
S-II	Pressurization	2.40	13
SM	Reaction Control	2.33	14
LEM	Guidance, Navigation and Control	2.04	15
LEM	Reaction Control System	1.98	16
S-IVB	Propulsion	1.94	17
S-II	Electrical Power	1.88	18
S-IVB	Auxiliary Power Supply	1.78	19
S-IC	Propulsion/Mechanical	1.48	20
S-II	Propellant Feed	1.36	21
S-II	Measurement, Class B	1.19	22
S-II	All Others	1.19	22
S-IC	Flight Control	1.05	23
S-II	Propellant Management	1.02	24
S-IVB	Propellant Utilization	0.86	25
S-II	Engine Servicing	0.68	26
S-IC	Electrical	0.60	27
LEM	Miscellaneous	0.49	28
S-IC	Support	0.43	29
CSM	Miscellaneous	0.35	30
CM	Reaction Control	0.25	31
S-IVB	All Others	0.22	32
S-IC	Structures	0.17	33
S-IC	Instrumentation	0.15	34
CSM	Cryogenic Storage	0.14	35

*See List of Abbreviations.

Figure C.3-8. Relative Contribution of Systems to Space Vehicle Mission Unreliability

[redacted]

C.4 LAUNCH VEHICLE RELIABILITY ANALYSIS AND STATUS SUMMARY

The Apollo-Saturn V Launch Vehicle is comprised of the S-IC, S-II, S-IVB and Instrument Unit. The overall Apollo Saturn 504 Launch Vehicle success probability estimate, based on contractor predictions, is 0.76. The Launch Vehicle contributes approximately 40 percent of the unreliability of the Apollo-Saturn 504 Space Vehicle. The S-II and the S-IVB are the largest contributors to Launch Vehicle unreliability (42.2 percent and 35.6 percent respectively). Figure C.4-1 shows relative contributions of each Stage to the predicted Launch Vehicle unreliability. A more detailed discussion of these stages is given in subsequent paragraphs.

Published reliability prediction values were tabulated and compared to apportionment values (Figures C.4-2 and C.4-3). In the mission model, the Launch Vehicle Stages were represented at the Stage level for the S-IC Stage and the Instrument Unit. The S-II and the S-IVB were modeled at the major subsystem level.

The degradation of the predicted Launch Vehicle and Stage success probabilities as a function of mission time is shown in Figure C.4-4. Where significant changes in mission success probability occur, the graph is flagged. Those changes are analyzed below.

The time intervals of individual subphases vary from as low as five seconds between subphases 4 and 5 (See Figure C.4-4), to as high as 5280 seconds between subphases 10 and 11.* The change in the slope of the Launch Vehicle curve at point (1) is a result of the large differences of subphase time. Just prior to (1), the subphase time is five seconds (S-IC cutoff, separation, and S-II ignition). There is little reliability degradation in these five seconds compared to degradation in the next subphase (S-II burn), which is 260 seconds long.

The slope of the curve through the three subphases during S-II burn is greater than the slope charted for the following two subphases of S-IVB burn. This explains the abrupt change of slope at point (2).

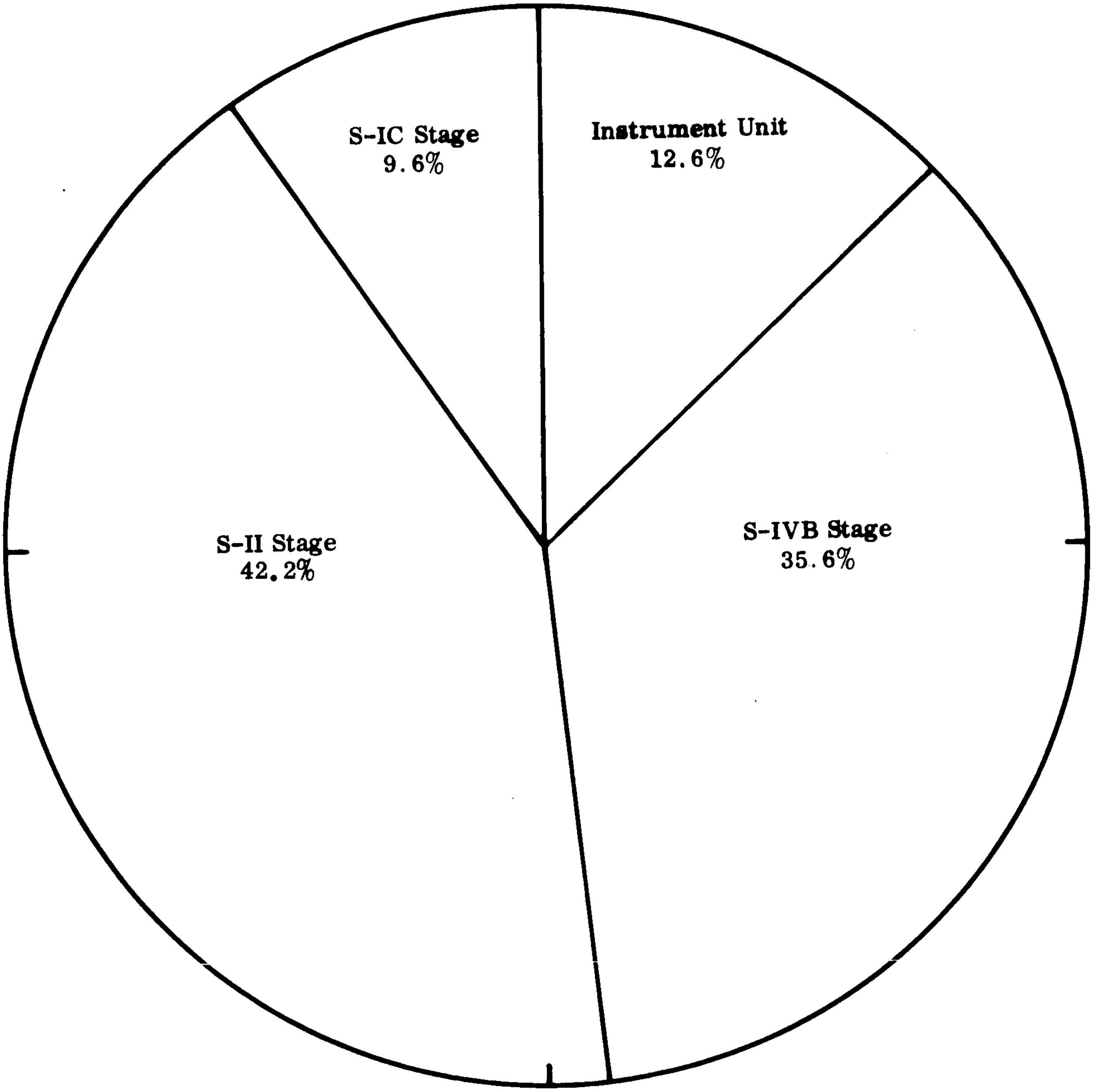
---

* See also Figure C.1-1.

[redacted]

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

Saturn V
Launch Vehicle



Note: 1. The Launch Vehicle accounts for 40.5 percent of the unreliability of the Space Vehicle.
2. Ground Operational Support System and crew functions were considered to have a reliability of 1.0 for this study.

Figure C.4-1. Percentage Contribution of Stages to Launch Vehicle Unreliability

[redacted]

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Apollo Program Specification	Ref.	Contract Work Statement	Ref.	Program Plan	Ref.	Contractor Published	Ref.	Apollo Program Office Value
S-IC Stage	.95	1			.95	10	.95	9	.9071*
S-II Stage	.95	1			.95	10	.95	11	.9155
S-IVB Stage	.95	1	.95	24	.95	10	.95	18	.9414*
Instrument Unit	.95	1			.992	10	.992	10	.992
Overall Apollo Saturn Launch Vehicle Mission Success Probability									

*Contractual reliability goals for engines used in calculations for stage.

CONFIDENTIAL

Figure C.4-2. Launch Vehicle and Stage Reliability Apportionment Values

[redacted]

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Contractor Published Reliability Apportionments	Contractor Published Reliability Prediction	Ref.	Difference: Apportionment Minus Prediction	Apollo Program Office Estimate
S-IC Stage	.950	.9757	5	-.0257	.9757
S-II Stage	.950	.893	14	+.057	.893
S-IVB Stage	.950	.910	18	+.040	.910
Instrument Unit	.942	.968	22	+.024	.968
Launch Vehicle Mission Success Probability					.76392

[redacted]

Figure C.4-3. Launch Vehicle and Stage Reliability Predictions and Prediction Versus Apportionment Comparisons

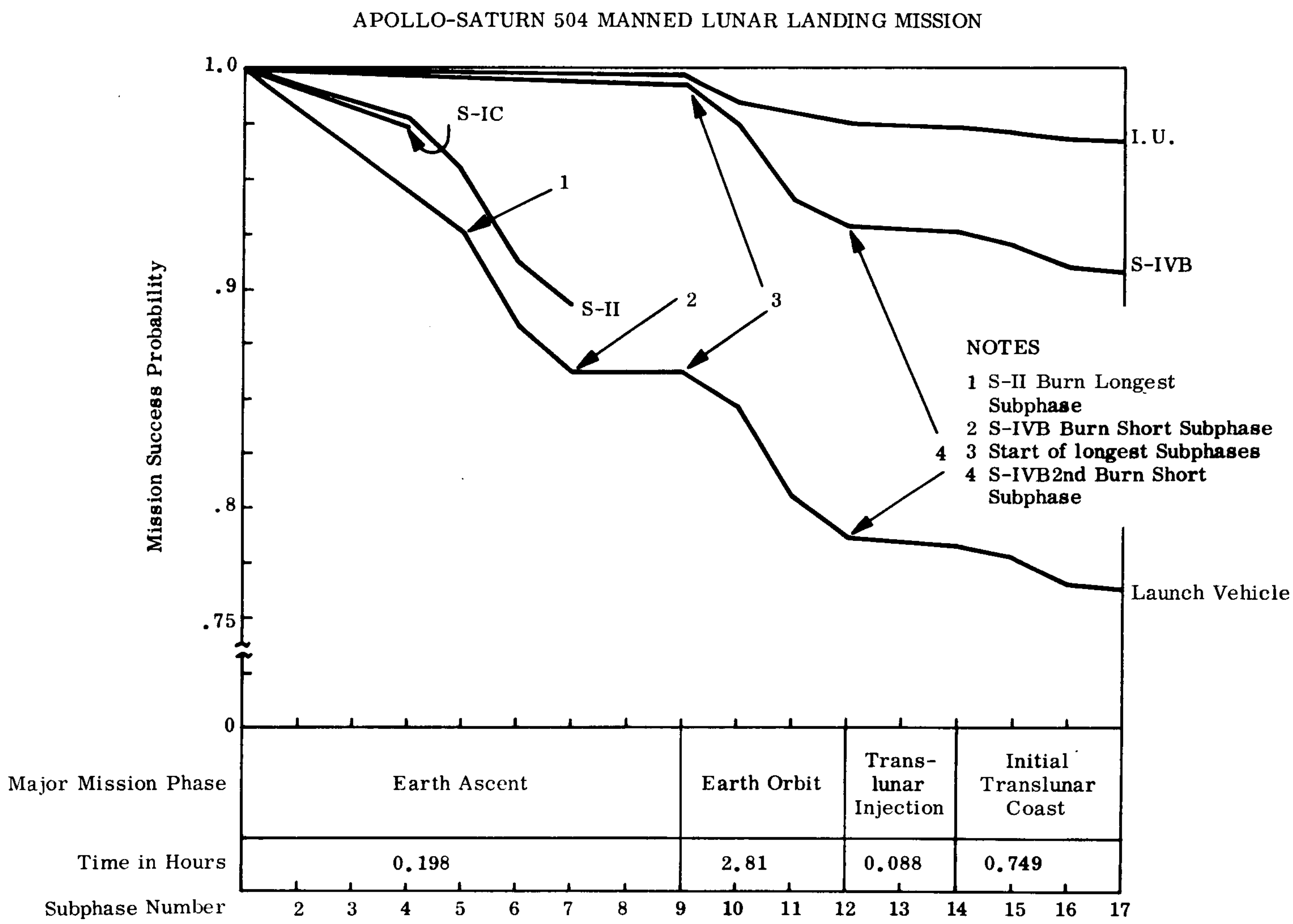


Figure C.4-4. Launch Vehicle and Stage Mission Success Probabilities versus Mission Phase

There is only a minor change of slope during the S-IVB burn period because the unreliability of the S-IVB Stage is spread out over longer total time interval.

During the 1031 seconds of system standby time in the Earth Parking Orbit phase, there is a considerable reliability degradation, radically changing the slope of the curve at point (3) on the chart.

At point (4) the change of slope is due to the much smaller time of the next two subphases (316 seconds) and the insignificant reliability degradation of the S-IVB Stage and Instrument Unit.

Reliability values for each stage subphase were calculated by proportioning the Stage unreliabilities on a time basis (i.e., the greatest portion of the unreliability was assigned to the longest subphase).

The S-II Stage contributes the most unreliability (42.2 percent) to the Launch Vehicle. The J-2 engines are the greatest contributors to that unreliability, primarily because of the relatively long run time of the five engine subsystems and present J-2 engine malfunction problems.

Several key equipments are significant contributors to overall Launch Vehicle unreliability of 40 percent. These are: the duct gimbal joints and ducting bellows (S-IC Stage); J-2 Engines (S-II and S-IVB Stages), the auxiliary propulsion engines (S-IVB Stage), and a selector switch in the S-IVB Stage. Each item is detailed in subsequent paragraphs dealing with the individual stages.

C.4.1 S-IC STAGE

C.4.1.1 System Configuration

The S-IC system configuration considered in this analysis is described in Reference 9 and in notes obtained from the Boeing Company's S-IC systems course.

C.4.1.2 Analysis Data

The S-IC stage was represented at the stage level in the simulation model because of limited contractor reliability prediction data. The contractor's model assumed that a failure in the instrumentation system would be cause for abort, whereas during a 504 mission the decision to abort will depend on <u>what</u> equipment in the stage has failed. Nevertheless, the contractor's reliability prediction value for the stage was used for the computation.

C.4.1.3 Results and Conclusions

The relative contribution of the S-IC Stage to Launch Vehicle predicted unreliability is approximately 10 percent. The contractor's documented reliability apportionment goal is 0.95 and the reliability prediction is 0.9757. Planned static tests and data obtained from Apollo-Saturn 501, 502 and 503 flights will provide additional confidence in meeting the reliability goal for the S-IC stage.

Figures C.4-5 and C.4-6 list the apportionments and predictions for stage subsystems and give a comparison of these values. In all cases, predicted values exceed the apportioned values.

The propulsion-mechanical system is the greatest contributor (38 percent) to predicted S-IC Stage unreliability. (Figure C.4-7 shows the relative unreliabilities of the major stage subsystems.) This percentage reflects high incidences of rupture and leaks in gimbal duct joints.

Listed below are the top ten contributors to S-IC stage unreliability. All are part of the propulsion mechanical system (Reference 6).

Item	Criticality Number*
1. Gimbal joints	7287
2. Ducting bellows	3130
3. Helium lines	1785
4. Retro-rocket motors	1544

* These contractor numbers reflect the relative magnitude of equipment unreliability.

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Apollo Program Specification	Ref.	Contract Work Statement	Ref.	Program Plan	Ref.	Contractor Published	Ref.	Apollo Program Office Value
S-IC Stage	.95	20			.95	10			.9071*
<u>Structures</u>							.9976	9	
<u>Propulsion/Mechanical</u>							.9805	5	
Fuel Pressure							.9938	9	
Fuel Delivery							.9966	9	
LOX Pressure							.9987	9	
LOX Delivery							.9983	9	
Engine Purge							.9999	9	
Control Pressure							.9998	9	
Retro-Rocket Motors (8)							.9981	9	
F-1 Engines							.9950	5	
<u>Support</u>							.9944	9	
<u>Electrical</u>							.9921	9	
Power Systems							.99892	5	
LOX Fill and Delivery							.99994	5	
Fuel Fill and Delivery							.99947	5	
Control Pressure and Purge							.99994	5	
Engine Start and Heater							.99994	5	
Inboard Cutoff							.99770	5	
Outboard Cutoff							.99773	5	
Range Safety							.99994	5	
Separation							.99990	5	
Fluid Control							.99990	5	
Stage Separation							.99859	5	
Malfunction Detection							.99971	5	
<u>Flight Control</u>							.9863	5	
Fluid Power							.9956	9	
Thrust Vectoring							.9944	5	
Control Instruments							.9963	5	
<u>Instrumentation</u>							.9980	9	

*Contractual reliability goals for engines used in calculation for stage

Figure C.4-5. S-IC Stage Reliability Apportionment Values

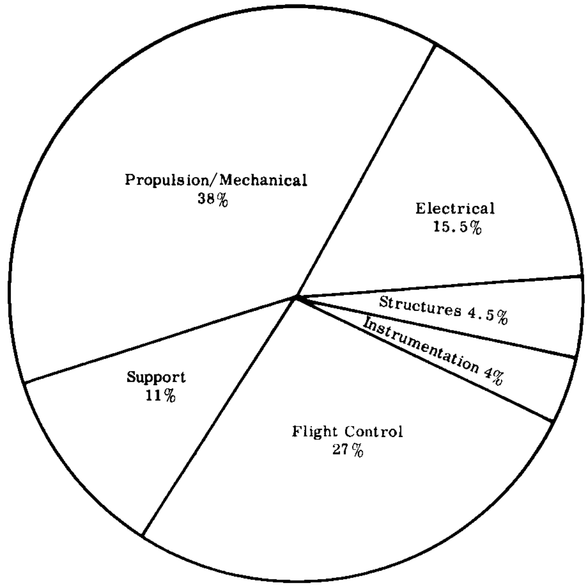
APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Contractor Published: Simulation Assessment	Contractor Published: Probability Analysis	Ref.	Difference Apportionment - Prediction	Apollo Program Office Estimate
S-IC Stage at Systems Level		.9757	5	+.0257	.9757
Structures					
Propulsion/Mechanical	.9892		5	+.0087	
Fuel Pressure	.9974		5	+.0036	
Fuel Delivery	.9995		5	+.0029	
LOX Pressure	.9999		5	+.0012	
LOX Delivery	.9985		5	+.0002	
Engine Purge	.9999		5	0	
Control Pressure	.9999		5	+.0001	
Retro-Rocket Motors (8)	.9989		5	+.0008	
F-1 Engines	-			-	
Support	-			-	
Electrical	-			-	
Power Systems		.999997	5	+.001077	
LOX Fill and Delivery		.999999	5	+.000059	
Fuel Fill and Delivery		.999983	5	+.000513	
Control Pressure and Purge		-		-	
Engine Start and Heater		-		-	
Inboard Cutoff		.999982	5	+.002282	
Outboard Cutoff		.999860	5	+.002130	
Range Safety		.999999	5	+.000059	
Separation		.999999	5	+.000099	
Fluid Control		.999978	5	+.000078	
Stage Separation		.999988	5	+.001398	
Malfunction Detection		-		-	
Flight Control	.9882		5	+.0019	
Fluid Power	.9975		5	+.0019	
Thrust Vectoring	-			-	
Control Instruments	-			-	
Instrumentation	-			-	

Figure C.4-6. S-IC Stage Reliability Predictions and Prediction Versus Apportionment Comparisons

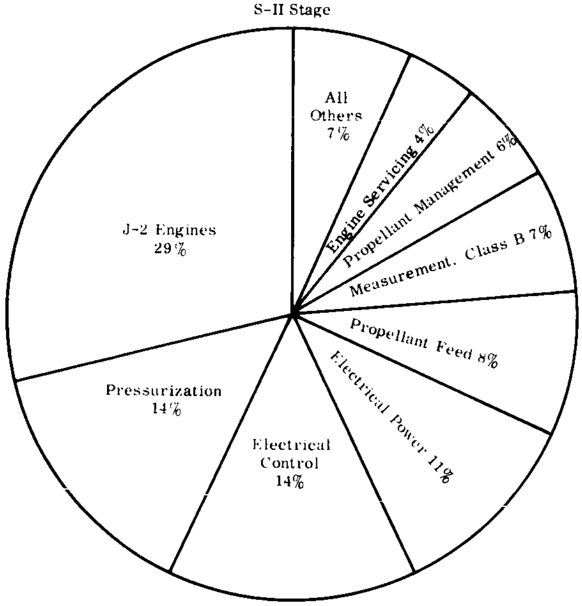
APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

S-IC Stage



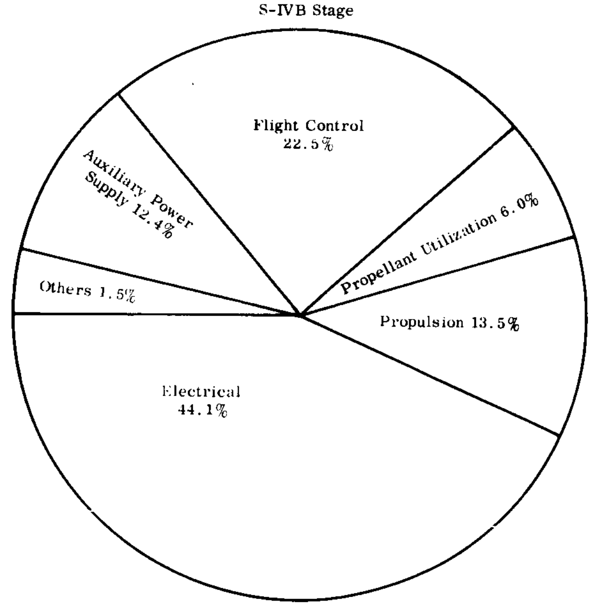
Note: The S-IC stage accounts for 3.9 percent of space vehicle unreliability

S-II Stage



Note: The S-II stage accounts for 17.1 percent of space vehicle unreliability

S-IVB Stage



Note: The S-IVB stage accounts for 14.4 percent of space vehicle unreliability

Figure C.4-7. Stage Systems Contributions to Stage Unreliability

	Item	Criticality Number*
5.	Tubing fittings	625
6.	Engine 4-way control valve	490
7.	Gas generator fuel line	350
8.	Pre-valves	212
9.	Turbine	197
10.	Gas generator ball valve	180

C.4.1.4 S-IC Stage Problem Areas

The S-IC Stage has several configuration differences from Vehicles 501, 502 and 503. The structure will have several major weight reducing changes that apparently will not be flight tested prior to the Apollo Saturn 504 flight.

1. The "Y" rings connecting the sides and domes of the two tanks will have "T" slots milled out to reduce the stage weight by 5000 lbs.
2. Changes in fuel tank bellows and LOX tank baffles will reduce weight by 400 lbs.
3. Removal of visual instrumentation and camera equipment will reduce weight by 1600 lbs.
4. Miscellaneous changes will reduce weight by 360 lbs.

These structural changes affect reliability and consequently are being investigated by Marshall Space Flight Center.

C.4.1.5 Gimbal Duct Joint Leakage

The gimbal duct joints which serve as part of the helium delivery lines inside the LOX tank are critical. Failure of the helium gimbal duct joints will result in helium leakage. This failure may cause the following three failure modes of the Vehicle:

a. Rupture of the LOX tank (11 percent contribution to stage unreliability).
b. RP-1 turbo pump cavitation (8 percent contribution to stage unreliability).
c. RP-1 tank collapse (2 percent contribution to stage unreliability).

The Marshall Space Flight Center is conducting a reliability analysis of the gimbal joint problem and will submit data on their findings.

C.4.1.6 Retro-Rockets

The reliability of individual retro-rockets of 0.996 as predicted by the contractor (Reference 1), is higher than that predicted for similar applications by the Manned Space Flight Center (Reference 18) and North American Aviation, Inc. (Reference 28). In Reference 18 and 28 values are 0.995, and 0.993 respectively. The probability of the occurrence of a catastrophic failure assumed by the contractor, is lower than currently noted (Reference 24). Rationale for this prediction was not available for evaluation but this variation is being investigated.

C.4.1.7 F-1 Engine

The latest F-1 engine Progress Letter (Reference 8), states that combustion instability continues to be a problem with the Block II (F-1 engine flight configuration) injector. Modifications to the injector are being evaluated constantly during the test program. During the April-May 1965 reporting period, one engine test was cut off due to rough combustion during the start-up transient (however, it occurred in an excluded test), and one other engine experienced a combustion disturbance after approximately 100 seconds of run (self-damped before cutoff signal). Although there were no declared failures, these continuing problems seriously affect reliability findings.

C.4.1.8 Data and Information Available

Information on the S-IC Stage has been available in greater quantity and on a more current basis during the past quarter. Further reliability information is required in the areas of Structures, Support (umbilical connection plates), Electrical, Flight Control (except for Thrust Vectoring), Instrumentation and the Ground Operational Support System pertaining directly to the S-IC Stage. A level III model review meeting at Marshall Space Flight Center will examine the affect of these problems on apportioned reliability goals.

C.4.2 S-II STAGE

C.4.2.1 System Configuration

The S-II Stage system configuration considered in the following paragraphs is described in Reference 12.

C.4.2.2 Analysis Data

The contractor (Reference 12) documented reliability prediction value was used for the computations. In the simulation model, the S-II Stage was represented at the major subsystem level.

C.4.2.3 Results and Conclusions

The present predicted reliability of the S-II Stage is 0.893, which contributes 42.21 percent to the unreliability of the Launch Vehicle.

Contractor stage and subsystem reliability apportionments (Reference 11) and predictions (Reference 12) are given in Figures C.4-8 and C.4-9. The systems have been ranked in Figures C.4-8 and C.4-9 from the greatest positive difference to the greatest negative difference between apportioned and predicted reliabilities.

Figure C.4-7 illustrates how the reported unreliability of the S-II Stage systems is distributed. The figures shown are based upon data from contractor documents (Reference 12). The J-2 engines are the major contributor (29 percent) to stage unreliability. With the exception of the J-2 engine program, very little data is available for evaluating reliability improvement. The contractor has no requirement to perform a criticality analysis on this stage.

The reliability apportionment of one J-2 engine is 0.99 (Reference 11), with a requirement to demonstrate 0.95 reliability by completing 60 tests with three or less failures (Reference 15). These reliability goals have been achieved (Reference 12). The reliability requirement of 0.99 did not specify the number of tests required for engine qualification (Reference 10).

The J-2 is a comparatively new engine design. The most critical technical problem is engine start. J-2 engine reliability demonstrations have shown a total of nine failures, five of which occurred during the start cycle (Reference 16). As a consequence, the J-2 engine start sequence is being investigated. The last two engine failures occurred during mainstage. One failed at 21.4 seconds due to leakage in the augmented spark ignitor assembly and injector mechanical interface. The other failure occurred at

[redacted]

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Apollo Program Specification	Ref.	Contract Work Statement	Ref.	Program Plan	Ref.	Contractor Published	Ref.	Apollo Program Office Value
S-II Stage	.95				.95		.95	11	.9155
Pressurization							.997240	11	
Electrical Control							.994000	11	
Electrical Power							.997161	11	
Instruments and Converter (Measurements, Class B)							.999025	11	
Propellant Feed							.996463	11	
Propellant Management							.997169	11	
Thermal Control							.999000	11	
Telemeter (PCM, SS, and PAM)							.999025	11	
Engine Servicing							.995774	11	
Flight Control Electronics							.998642	11	
Engine Compartment Purge							.999437	11	
Antennae							.999475	11	
Structure							.997629	11	
Propulsion, J-2 Engines							.950400	11	
Command and Tracking (Tracking and MISTRAM)							.999025	11	
Engine Actuation							.998945	11	
Separation							.997400	11	
Destruct (Propellant Dispersion-Prediction)							.996216	11	
Emergency Detection							.997836	11	
Ullage							.999367	11	

Figure C.4-8. S-II Stage Reliability Apportionment Values

[redacted]

[redacted]

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Contractor Published	Ref.	Difference: Apportionment Minus Prediction	Apollo Program Office Estimate
S-II Stage	.89317	14	+.0583	.893*
Pressurization	.976247	12	+.020993	
Electrical Control	.976325	12	+.017675	
Electrical Power	.981003	12	+.016158	
Instruments and Converter (Measure, Class B)	.988216	12	+.010709	
Propellant Feed	.987147	12	+.009316	
Propellant Management	.989512	12	+.007657	
Thermal Control	.996258	12	+.002742	
Telemeter (PCM, SS, and PAM)	.996623	12	+.002402	
Engine Servicing	.993696	12	+.002078	
Flight Control Electronics	.998346	12	+.000306	
Engine Compartment Purge	.999745	12	-.000308	
Antennae	.999996	12	-.000521	
Structure	.998323	12	-.000694	
Propulsion, J-2 Engines	.951108	12	-.000708	
Command and Tracking (Tracking and MISTRAM)	.999965	12	-.000940	
Engine Actuation	.999947	12	-.001002	
Separation	.999263	12	-.001863	
Destruct (Propellant Dispersion Prediction only)	.999972	12	Not Applicable	
Emergency Detection	Not Given			
Ullage				

*Based on prediction values.

[redacted]

Figure C.4-9. S-II Stage Reliability Predictions and Prediction versus Apportionment Comparisons

142 seconds. The suspected cause was short circuit in the electrical control assembly. Improvements in J-2 start characteristics and performance must be accomplished in order to meet engine qualification reliability requirements.

C.4.3 S-IVB STAGE

C.4.3.1 System Configuration

The S-IVB stage configuration used corresponds to that used by Douglas Aircraft Company to construct the reliability model of the Saturn V/S-IVB Stage (Reference 17).

C.4.3.2 Analysis Data

The contractor data and the reliability model of the Saturn V/S-IVB (Reference 17) used for this analysis is dated 15 April 1965. No new data has become available since that date. In the mission simulation model, the S-IVB Stage was represented at the major subsystem level.

C.4.3.3 Results and Conclusions

The overall probability of S-IVB stage mission success predicted by the contractor is 0.910. The relative contribution of the S-IVB Stage to the predicted Launch Vehicle unreliability is 35.55 percent. Figures C.4-10 and C.4-11 show reliability apportionment and prediction values and their comparisons.

C.4.3.4 Problem Areas

The electrical system is the major contributor (44.1 percent) to predicted unreliability of the S-IVB Stage. This is primarily due to the unreliability of the selector switch and the sequencer mounting assembly which appear among the ten top contributors to unreliability in the critical component criticality list. The relative contributions by other major S-IVB subsystems to stage unreliability are shown in Figure C.4-7.

The ten top contributors to stage unreliability among the S-IVB systems are ranked by the contractor as follows (Reference 18).

[redacted]

System	Apollo Program Specification	Ref.	Contract Work Statement	Ref.	Program Plan	Ref.	Contractor Published	Ref.	Apollo Program Office Value
S-IVB Stage	.95		.95		.95		.9500	18	.9414*
Structure							.99989	18	
Propulsion							.99370	18	
Propellant Utility							.99520	18	
Flight Control							.98500	18	
Auxiliary Power Supply							.993800	18	
Separation							.997900	18	
Range Safety							.996600	18	
Environmental Control							.999640	18	
Data Acquisition							.993800	18	
Electrical							.993800	18	

*Contractual reliability goal for engineers used in calculation for stage.

Figure C.4-10. S-IVB Stage Reliability Apportionment Values

[redacted]

[redacted]

System	Contractor Published	Ref.	Difference Apportionment Prediction	Apollo Program Office Prediction Estimate
S-IVB Stage	.910	18	+.0400	Same as Contractor Published (First Column)
Structure	.999890	18	-	
Propulsion	.98800	18	+.00570	
Propellant Utility	.994700	18	+.00050	
Flight Control	.980000	18	+.0050	
Auxiliary Power Supply	.989000	18	+.0048	
Separation	.999956	18	-.002056	
Range Safety	.999680	18	-.003080	
Environmental Control	.999170	18	+.000470	
Data Acquisition	.999780	18	-.00598	
Electrical	.961000	18	+.32800	

Figure C.4-11. S-IVB Stage Reliability Predictions and Prediction Versus Apportionment Comparisons

[redacted]

Item	Associated Subsystem	Criticality Number*
1. Selector Switch	Electrical	35000
2. Engine, Auxiliary Propulsion	Flight Control	9200
3. Modules (Helium Fill)	Flight Control	5400
4. Electronic Assembly	Propellant Utilization	5100
5. Pump Hydraulic Auxiliary	Auxiliary Power Supply	3200
6. Cable Assembly (Electrical Distribution)	Electrical	2300
7. Engines, Auxiliary Propulsion, 1750 lbs. Thrust	Flight Control	2000
8. Sequencer Mounting Assembly	Electrical	2000
9. Separator, Vent	Auxiliary Power Supply	1700
10. Pump, Hydraulic, Thermal Isolator Assembly	Auxiliary Power Supply	1500

The contractor (Douglas) reliability analysis (Reference 17) of the four interstage retro-rockets does not appear to take adequate account of the catastrophic failure mode. The contractors reliability assessment (Reference 17) indicates that this item contributes only 0.4 percent of the stage unreliability. However, failure probability estimates indicate that the contribution to total stage unreliability should be about 12 percent. (Reference 9).

C.4.4 INSTRUMENT UNIT

C.4.4.1 System Configuration

The configuration used for the Instrument Unit was derived from the Saturn Program Development Plan (Reference 10).

C.4.4.2 Analysis Data

Contractor data (Reference 21) and system information was used to represent the Instrument Unit in the mission simulation model at the stage and major subphase level. Because of lack of contractor documented reliability data, a reliability of 1.0 was assumed for the Guidance and Control system, the Electrical System, Structures, and Instrumentation. The reliability value given in Reference 22 was used for the thermal condition system.

* These contractor numbers reflect the relative magnitude of equipment unreliability.

C.4.4.3 Results and Conclusions

The present predicted reliability of the Instrument Unit is .968 which contributes 12.6 percent to the predicted unreliability of the Launch Vehicle.

The relative unreliability of the major systems within the Instrument Unit was not computed. Figures C.4-12 and C.4-13 show the tabulation of reliability apportionments and predictions for the Instrument Unit.

A Level III model review meeting will be arranged with the contractor to cover data describing Instrument Unit reliability status, including the following items: reliability models, failure mode effects analysis, failure data and rationale, failure reports, test results, configuration changes, and reliability analysis of changes and system impact with respect to reliability.

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Apollo Program Specification	Ref.	Contract Work Statement	Ref.	Program Plan	Ref.	Contractor Published	Ref.	Apollo Program Office Value
Instrument Unit					.992		.990 .992	20 10	.992
Structures									
Guidance and Control									
Electrical									
Thermal Conditioning									
Instrumentation									

Figure C.4-12. Instrument Unit Reliability Apportionment Values

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System	Contractor Published	Ref.	Difference Apportionment Prediction	Apollo Program Office Prediction Estimate
Instrument Unit	.972	21	+.028	.968
	.968	22	+.024	
Structures				
Guidance and Control				
Electrical				
Thermal Conditioning	.99635	19		
Instrumentation				

Figure C.4-13. Instrument Unit Reliability Predictions and Prediction Versus Apportionment Comparisons

C.5 SPACECRAFT RELIABILITY ANALYSIS AND STATUS

The Apollo Spacecraft includes the Command Service Module and the Lunar Excursion Module. Mission success probability for the Spacecraft, based on contractor predictions, is 0.834. Approximately 60 percent of the mission unreliability of the Apollo Space Vehicle is due to the Spacecraft. With this percentage taken as a base, the Command Service Module contributes 69 percent and the Lunar Excursion Module contributes 31 percent to spacecraft unreliability.

The figure below shows the current status of reliability apportionments and predictions at the spacecraft level.

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

Item / Data and Source	Center/Contractor Reliability Values		Current Apollo Program Office Prediction Estimate
	Apportionment Value (**)	Prediction Value (**)	
Mission Success Probability	0.950	0.835	0.682
Crew Safety Probability	0.999		(*)

(*) Apollo Program Office estimate considers crew safety on an overall Mission basis only.
(**) Based on the values tabulated in Figures C.5-6, C.5-7, C.5-10, and C.5-11.

Figure C.5-1. Spacecraft Reliability Values

The Command Service Module Guidance, Navigation and Control System and the Environmental Control System are the leading contributors (see Figure C.5-2) to Spacecraft unreliability. Figure C.5-3 shows the current status and compares reliability apportionments and predictions for the Lunar Excursion and Command Service Modules.

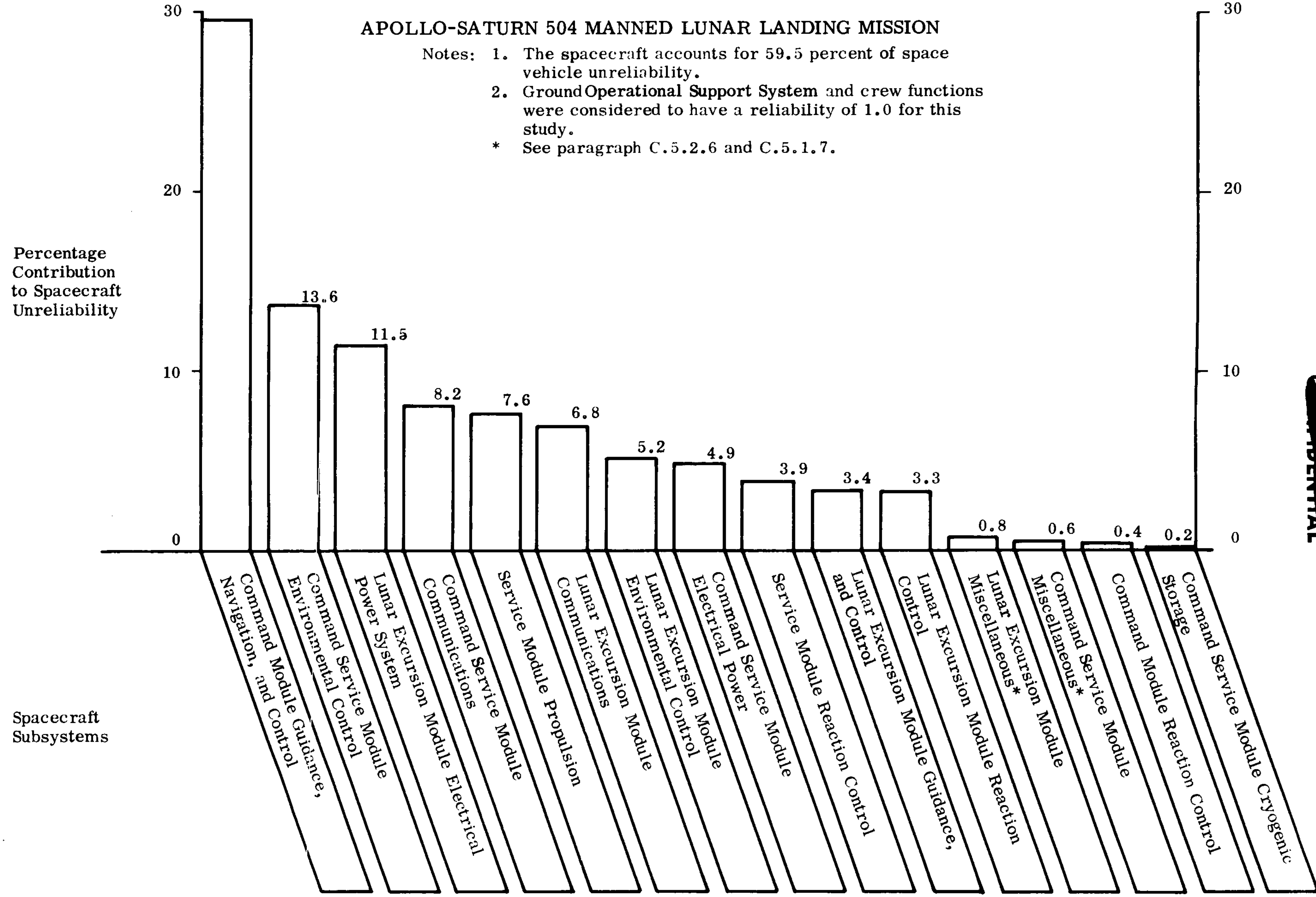


Figure C.5-2. Percentage Contribution of Systems to Spacecraft Unreliability

[redacted]

APOLLO-SATURN 504 MANNED LUNAR MISSION

	Reliability Apportionment								Reliability Prediction and Comparison			
System	Apollo Program Specification	Ref.	Contract Work Statement	Ref.	Program Plan	Ref.	Contractor Published	Ref.	Contractor Published	Ref.	Difference: Apportion-ment Minus Prediction	Apollo Program Office Estimate
Command Service Module	0.96	1			0.9638	30	0.9638	38	0.944032	38	+0.019818	0.7662
Lunar Excursion Module and Adapter	0.98	1	0.984	66	0.984	66	0.987	42	0.8840	42	+0.10300	0.88942

Figure C.5-3. Command Service and Lunar Excursion Module Reliability Apportionment, Prediction Values, and Comparisons

[redacted]

The fifteen most critical components in spacecraft systems, accounting for 50 percent of Spacecraft unreliability, are shown below:

Component	System*
Glycol Valves and Sensors	CSM/ECS
Flight Director Attitude Indicator 1	CM/GNC
Flight Director Attitude Indicator 2	CM/GNC
Gyro Package 1	CM/GNC
Gyro Package 2	CM/GNC
EVA Communications	LEM COMM
Inverter 3	CSM/EPS
Guidance Computer	CM/GNC
Gyro Display Coupler	CM/GNC
Atmosphere Revitalization Group	LEM ECS
Engine Assembly	LEM RCS
Tanks	SM/PRO
Heat Transfer Group	LEM ECS
Accelerometer	CM/GNC
Delta V Indicator	CM/GNC

For more detail refer to the paragraphs discussing the individual subsystems.

Command Service Module and Lunar Excursion Module success probabilities during major mission phases are shown in Figure C.5-4. Those portions of the curves exhibiting the largest reliability degradation are flagged on the chart. A summary discussion is presented below.

C.5-1 COMMAND SERVICE MODULE SUCCESS PROBABILITY

The reliability degradation for the Command Service Module occurs primarily during four major mission phases shown in Figure C.5-4. With the exception of the Earth Orbit phase, the major unreliability contribution occurs during translunar and transearth periods and lunar stay. Since these phases encompass long periods of time, the

(*) See list of abbreviations.

COMMENTS

The following identifies the subsystem and its percentage contribution to the unreliability of the major mission phases flagged.

LEM

1 EPS - 100 Percent

2 EPS - 46 Percent
RCS - 27 Percent
G&C - 17.5 Percent

3 EPS - 43.3 Percent
Comm - 43.3 Percent

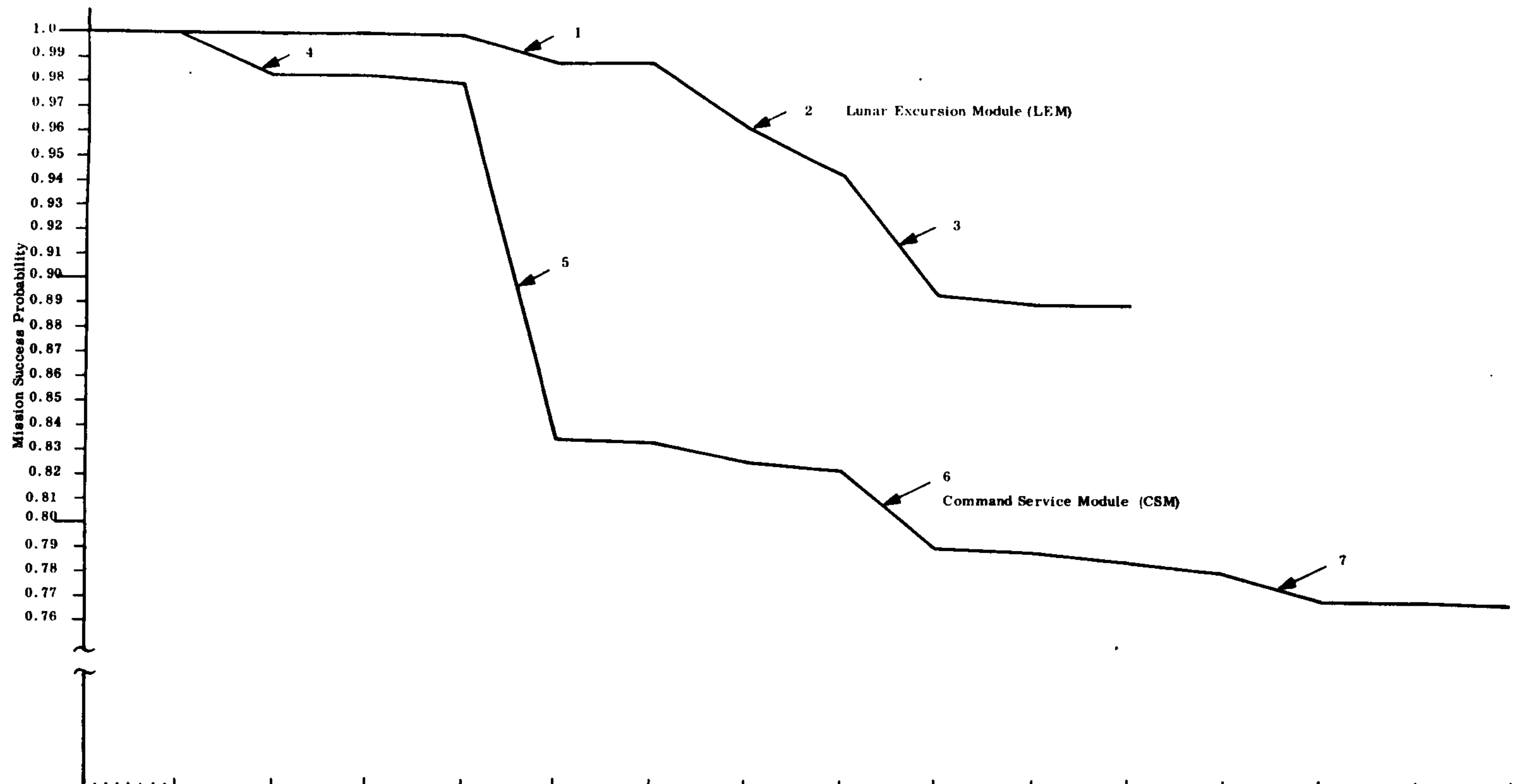
CSM

4 GNC - 49.2 Percent
SM RCS - 22.8 Percent
EPS - 15 Percent

5 GNC - 56.7 Percent
Comm - 12.4 Percent

6 ECS - 38.4 Percent
SM PRO - 23.7 Percent
EPS - 18.6 Percent
SM RCS - 17.5 Percent

7 ECS - 52.7 Percent
GNC - 40.3 Percent



	Earth Ascent	Earth Orbit	Translunar Injection	Initial Translunar Coast	S-IVB Jettison to Lunar Orbit Insertion	Lunar Orbit Insertion	Lunar Orbit Coast to LEM Separation	CSM Solo/LEM Separation and Descent	Hover to Touchdown and Lunar Stay	LEM Ascent	Lunar Orbit Coast to Transearth Injection	Transearth Injection	Transearth Coast	Entry	Parachute Descent
Major Mission Phase Time In Hours	0.198	2.81	0.088	0.749	60.4	0.097	3.72	1.45	34.760	1.28	3.577	0.026	88.843	0.425	0.118
Subphase Numbers	2-9	10-12	13-14	15-17	18-28	29-32	33-34	35-40	41-51	52-66	67-69	70	71-77	78-79	80

Figure C.5-4. Command Service and Lunar Excursion Module Probabilities of Mission Success versus Major Mission Phase long equipment operating times have a major impact on mission reliability. The Earth Orbit phase ranking is due to all equipments having to be in operating condition prior to Translunar Injection.

The following comments are applicable to the mission phases in question:

C.5.1.1 Flag No. 4 (Earth Orbit)

The principal contributors to the unreliability of the Earth Orbit phase are Guidance, Navigation, and Control (49.2 percent), Service Module Reaction Control (22.8 percent), and Electrical Power (15 percent). In each case the primary reason for the unreliability contribution is the operating requirement that most Command Service Module equipments be operational.

C.5.1.2 Flag No. 5 (S-IVB Jettison to Lunar Orbit Insertion

During this phase, principal contributions to unreliability are made by Guidance, Navigation, and Control (56.7 percent) and Communications (12.4 percent). In general, the reasons for the unreliability contribution are: ground rules require abort in event of any communications or guidance failures, the guidance equipment is on continuously throughout this phase, and there are heavy demands on the communications equipment during this phase.

C.5.1.3 Flag No. 6 (Hover to Touchdown and Lunar Stay)

The major contributors to unreliability during this phase are Environmental Control (38.4 percent), Service Module Propulsion (23.7 percent), Electrical Power (18.6 percent), and Service Module Reaction Control (17.5 percent). During this phase, mission success and abort success criteria are essentially identical. System contribution to unreliability is affected primarily by ability to take advantage of equipment redundancies. It is emphasized that, when this is the case, the Environmental Control System rather than the Guidance Navigation Control becomes the principal contributor to spacecraft unreliability.

C.5.1.4 Flag No. 7 (Transearth Coast)

As in the previous phase, mission success and abort success criteria are essentially identical. The Guidance, Navigation, and Control system again becomes a principal contributor to unreliability when it is turned on for the return flight. Then, however, the Environmental Control System displays the greater unreliability because other subsystems are functioning under operational criteria which allow full use of all equipment redundancies.

C.5.2 LUNAR EXCURSION MODULE SUCCESS PROBABILITY

The maximum unreliability during the various mission phases shown in Figure C.5-4, occurs during those intervals indicated by flag numbers 1, 2, and 3. The longest phase times are primarily responsible for the reliability degradation, indicated by flag numbers 1 and 3. During the phases indicated by flag number 2, checkout of Lunar Excursion Module systems and Lunar Descent occurs. Both events contribute to unreliability. The following additional comments are applicable to the phases flagged 1, 2, and 3.

C.5.2.1 Flag No. 1 (S-IVB Jettison to Lunar Orbit Insertion)

The Environmental Control System is the only contributor to LEM mission failure during this interval, since it was assumed that other Lunar Excursion Module failures could not be detected until crew boarding of the Lunar Excursion Module.

C.5.2.2 Flag No. 2 (Lunar Orbit Coast to Lunar Excursion Module Separation and Descent

The principal contributors to unreliability during this mission period are Electrical Power (46 percent), Reaction Control (27 percent), and Guidance Control (17.5 percent). The reasons for this degradation are that all systems are turned on and checked out in this phase. Consequently, any failures which may have occurred earlier in the mission will be detected. Also, this is the period of Lunar Descent when stringest abort ground rules are in effect.

C.5.2.3 Flag No. 3 (Hover to Touchdown and Lunar Stray)

During this period, Lunar Excursion Module reliability is degraded primarily by Electrical Power (43.3 percent) and by Communications (43.3 percent). The Electrical Power System contribution to unreliability is greatly influenced by mission success criteria. The Communications contribution to mission failure is due to the low reliability of Extra-Vehicular Communications.

C.5.3 CONCLUSIONS

General conclusions which can be drawn on the basis of this analysis include the following:

(1) Equipment operational status required for mission continuation during the translunar portion of the mission causes a large amount of reliability degradation because of abort criteria and lengthy, equipment "on" time. This is particularly true in the case of Command Service Module-Guidance, Navigation, and Control System in which a significant reliability improvement could be made if the system were turned off during most of the Translunar Coast phase.

(2) The Command Service Module-Guidance, Navigation, and Control Subsystem ranks first in unreliability with a percentage contribution of 29 percent to Spacecraft unreliability and 17.61 percent to mission unreliability (Figure C.5-2).

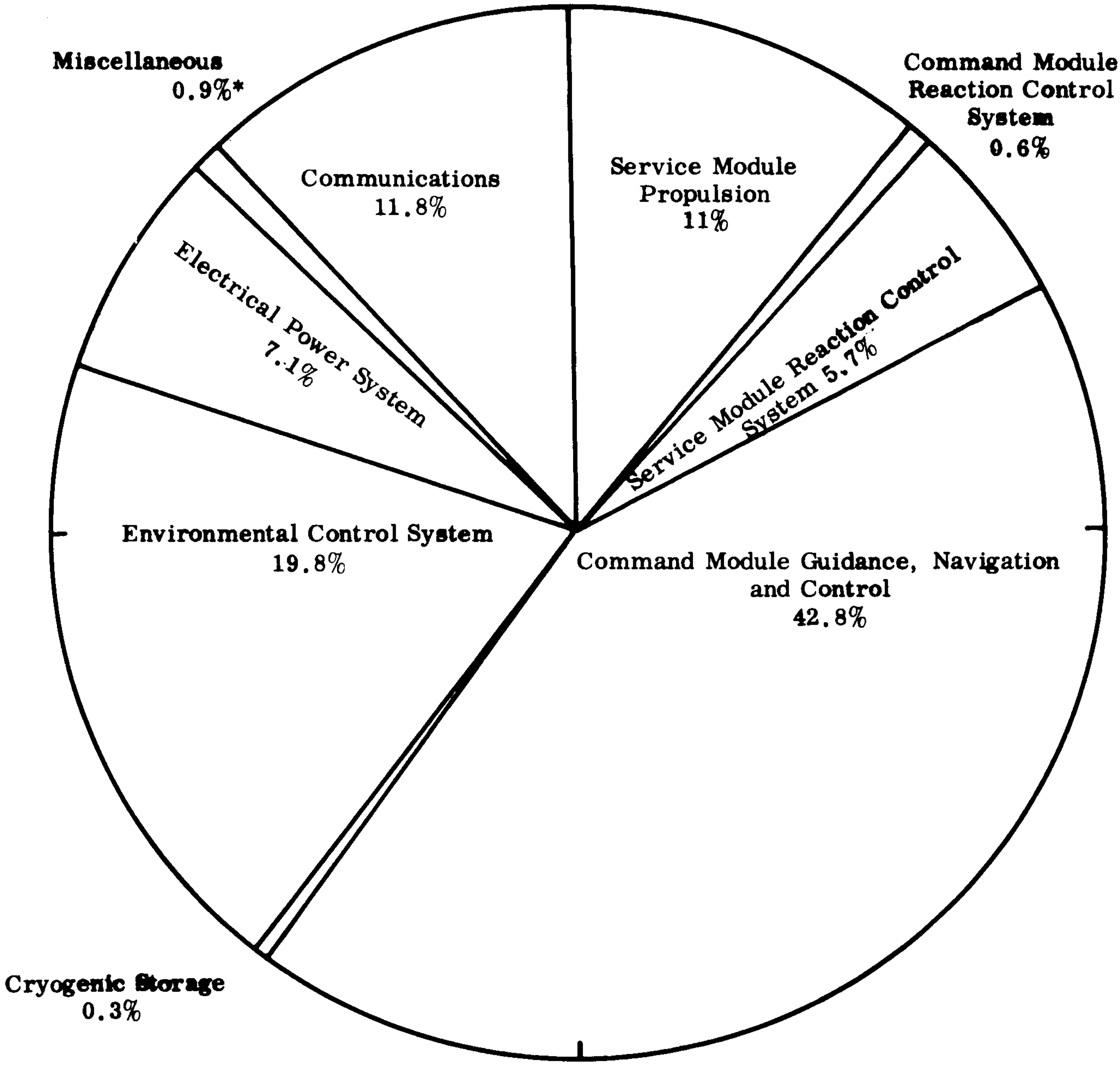
(3) The major causes of the unreliability of the Lunar Excursion Module are the four silver-zinc Descent Batteries in the Electrical Power System, all of which are required to operate until the end of a 34.7 hour lunar stay. A lunar stay of 20 hours, for example, would enhance this reliability because only three of the four batteries would be required, due to reduced energy requirements.

C.5.4 COMMAND SERVICE MODULE (CSM)

The individual CSM subsystem contribution to the overall Command Service Module mission unreliability is shown in Figure C.5-5. Figures C.5-6 and C.5-7 depict the current mission success and crew safety apportionments and predictions for the Command Service Module systems, as reported by contractors. In addition,

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

Command and Service Module



*Miscellaneous includes Structure, Emergency Detection System, Launch Escape System, Earth Landing System, Heat Shield, and Separation.

Notes: 1. The Command Service Module accounts for 41.1 percent of Space Vehicle unreliability.
2. Ground Operational Support System and crew functions were considered to have a reliability of 1.0 for this study.

Figure C.5-5. Percentage Contribution of Systems to Command Service Module Unreliability

CENTER/CONTRACTOR REPORT

System or Subsystem	Mission Success Reliability Apportionment	Ref.	Mission Success Reliability Prediction	Ref.	Difference: Apportionment minus Prediction	Apollo Program Office Estimate
Structures (All)	0.9999990/0.9999990	52/38	0.9999990	38	0.0	0.999999
Heat Shield	0.9999500/0.9999600	52/38	0.9999600	38	0.0	0.99996
Launch Escape System	0.9999982/0.9999982	52/38	0.9999982	38	0.0	0.9999982
Separation Systems	0.9999723/0.9999717	52/38	0.9999715	38	+0.0000002	0.9999715
Parachute Recovery	0.9999395/0.9999500	52/38	0.9999500	38	0.0	0.9999500
Earth Impact and Flotation*	0.9999950/0.9999750	52/38	0.9999750	38	0.0	0.9999750
Docking Mechanism	0.9990000/0.9999810	52/38	0.9999830	38	-0.000002	-
Electrical Power System	0.9953721/0.9954428	52/38	0.9959139	38	-0.00047	0.98174
Emergency Detection System	0.9999900/0.9999900	52/38	0.9999910	38	-0.000001	0.9999910
Environmental Control System	0.9960268/0.9961121	52/38	0.9960793	38	0.000033	0.94915
Space Suits (GFE)	0.9999825/0.9999837	52/38	0.9999855	38	-0.000002	-
Portable Life Support	0.9999183/0.9999188	52/38	0.9999290	38	-0.00001	-
Cryogenic Storage	0.9986819/0.9973378	52/38	0.9976119	38	-0.00027	0.99910
Integrated Electronics	0.9780470/0.9785097	52/38	0.9601975	38	+0.0183	-
Guidance, Navigation, and Control	-		-		-	0.88974
Instrumentation	-		-		-	-
Communications	-		-		-	0.96960
Command Module Reaction Control System	0.9935340/0.9996710	52/38	0.9988861	38	+0.000785	0.99845
Service Module Reaction Control System	0.9979500/0.9979795	52/38	0.9981650	38	-0.000186	0.98541
Service Module Propulsion System	0.9979282/0.9986802	52/38	0.9966314	38	+0.00205	0.97175
Overall Command Service Module	0.9638/0.9638512	52/38	0.9440332	38	+0.019818	0.76620

*Mission success occurs when the CM lands without exposing the crew to environments exceeding emergency limits

Figure C.5-6. Command Service Module (Block II) Mission Success Reliability Apportionments, Predictions, and Comparisons

[redacted]

CENTER/CONTRACTOR REPORT

System or Subsystem	Crew Safety Reliability Apportionment	Ref.	Crew Safety Reliability Prediction	Ref.	Difference: Apportionment Minus Prediction
Structures (All)	0.9999990/0.9999990	52/38	0.9999990	38	0.0
Heat Shield	0.9999500/0.9999600	52/38	0.9999600	38	0.0
Launch Escape System	0.9999600/0.9999600	52/38	0.9997631	38	+0.000197
Separation Systems	0.9999904/0.9999877	52/38	0.9999770	38	+0.000107
Parachute Recovery	0.9999395/0.9999500	52/38	0.9999500	38	0.0
Earth Impact and Flotation	0.9999950/0.9999750	52/38	0.9999750	38	0.0
Docking Mechanism	0.9999999/0.9999999	52/38	0.9999999	38	0.0
Electrical Power System	0.9999747/0.9999752	52/38	0.9999791	38	-0.0000039
Emergency Detection System	0.9999990/0.9999990	52/38	0.9999990	38	0.0
Environmental Control System	0.9999180/0.9999995	52/38	0.9992811	38	+0.000718
Space Suits (GFE)	0.9999976/0.9999978	52/38	0.9999981	38	-0.0000003
Portable Life Support	0.9999995/0.9999995	52/38	0.9999995	38	0.0
Cryogenic Storage	0.9999989/0.9999957	52/38	0.9999967	38	-0.000001
Integrated Electronics	0.9999450/0.9998974	52/38	0.9994883	38	+0.000409
Guidance, Navigation, and Control	--		--		--
Instrumentation	--		--		--
Communications	--		--		--
Command Module Reaction Control System	0.9999237/0.9998770	52/38	0.9992546	38	+0.00062
Service Module Reaction Control System	0.9999990/0.9999990	52/38	0.9999991	38	-0.0000001
Service Module Propulsion System	0.9999055/0.9999422	52/38	0.9992647	38	+0.000678
Overall Command Service Module	0.9995800/0.9995131	52/38	0.9969842	38	+0.00253

Figure C.5-7. Command Service Module (Block II) Crew Safety Reliability Apportionments, Predictions, and Comparisons

[redacted]

[redacted]

Figure C.5-6 contains a column which presents the current Apollo Program Office predictions. Two sets of contractor reliability values are shown. One set was taken from the Command Service Module Technical Specification Block II (Reference 52), while the other set was reported in the contractor's Thirteenth Quarterly Reliability Status Report (Reference 38). Level III review meetings will reconcile the discrepancies in the two sets of values.

A more detailed analysis of this study and comparison of the results with contractor estimates, as they pertain to the Command Service Module, is presented in subsequent paragraphs.

C.5.4.1 Command Service Module - Guidance, Navigation, and Control (GNC)

C.5.4.1.1 System Configuration

The Guidance, Navigation, and Control System configuration used in this analysis is based upon the minutes of Command Service Module Block II Guidance and Control Implementation Meetings begun in June 1964. This Block II system includes integration of the Manned Space Flight Network as the primary source of navigation data and the addition of certain stabilization and control functions to the Guidance and Navigation system. Increased redundancy in the Honeywell Stabilization and Control system is also a major design improvement in the Block II configuration.

C.5.4.1.2 Analysis Data

The Guidance, Navigation, and Control logic diagrams used reflect current lunar mission planning. The required system functions were based on the Apollo Mission Planning Task Force Design Reference Mission; the mission continuation ground rules used in this analysis correspond to those currently being used at the Manned Spacecraft Center (Reference 32). These ground rules state that all GNC equipment must remain operative to the initiation of Lunar Excursion Module Descent, whereupon no Guidance, Navigation, and Control equipment will be cause for abort until the Lunar Excursion Module returns. After that, mission success and crew safety objectives are identical, and the Command Module GNC system takes full advantage of its redundant configuration to complete the mission. These ground rules also correspond closely to the ground

[redacted]

rule applicable to the Spacecraft that the mission will be aborted when one more failure would result in loss of the crew. The failure rates for the Guidance and Navigation elements of the GNC system were derived from a contractor report issued in 1964 (Reference 33). A Manned Spacecraft Center data review meeting held on 17 August 1965 at the Massachusetts Institute of Technology Instrumentation Laboratory revealed that the failure rate values were within 10 percent of those previously reported in contractor documents.

The failure rates for the Stabilization and Control elements of the Guidance, Navigation, and Control system were obtained from minutes of a Block II implementation meeting held in August of 1964 (Reference 34). No updated values have since become available.

The equipment operating timeline profiles were extracted directly from the Design Reference Mission document (Reference 2). In many instances, "on-off" data for certain elements were missing, but knowledge of equipment requirements for various mission functions, along with information about electrical power application to portions of the GNC system, permitted estimates of operating times to be matched to the mission profile.

C.5.4.1.3 Results and Conclusions

The estimated system success probability for the Command Service Module Guidance, Navigation, and Control System is 0.88974. The success probability is low during the period from liftoff to Lunar Excursion Module separation in lunar orbit. In accordance with the ground rules (Reference 32), the Command Service Module GNC does not degrade the probability of mission success during the lunar excursion. From Lunar Excursion Module docking to mission termination, Guidance, Navigation, and Control System success probability is very high due to utilization of the redundancy designed into the Block II configuration.

The Guidance, Navigation, and Control System success probability can be significantly improved by decreasing the currently planned operating time of Guidance, Navigation, and Control equipment, especially during the Translunar Coast phase of the mission. During this phase, the ability to turn off one Flight Director Attitude Indicator and one Gyro Package would seem desirable. Further, the feasibility of free drift (all Guidance, Navigation, and Control equipment off or on standby) during most of this phase should be examined.

Over the entire mission, the components contributing most to Guidance, Navigation, and Control System unreliability are the following:

- Flight Director Attitude Indicator 1
- Flight Director Attitude Indicator 2
- Gyro Package 1
- Gyro Package 2
- Guidance Computer
- Gyro Display Coupler

A comparison of the present prediction estimate with that of the contractor cannot be made at this time because the contractor considers the GNC System part of the Integrated Electronics System and not a separate system.

C.5.4.2 Command Service Module - Environmental Control System

C.5.4.2.1 System Configuration

Used for this analysis was contractor (North American Aviation, Inc.) system configuration described by Environmental Control System schematic diagrams of May 1965 (Reference 35).

C.5.4.2.2 Analysis Data

The calculations are based on the CSM Block II Reliability Logic Diagrams, derived from a contractor document (Reference 2).

The equipment failure rates used are primarily contractor values, derived from the contractors' quarterly reliability status reports (e.g., Reference 36). The equipment timeline profiles were derived from the Design Reference Mission, Apollo Mission Planning Task Force document (Reference 2).

C.5.4.2.3 Results and Conclusions

The probabilities of system success and crew system (*) for the CSM Environmental Control System are 0.949 and 0.985, respectively. These values are lower than the contractor's predictions primarily because:

(1) The contractor does not include in his reliability logic diagrams the necessary instrumentation and displays.

(2) The contractor uses abort ground rules which differ in some respects from those used in the present analysis.

To illustrate the second point, the contractor assumes that the mission will be aborted only after the <u>secondary</u> suit loop compressor has failed, whereas the present analysis is based on the assumption that the mission will be aborted after the <u>primary</u> suit loop compressor fails. Consequently, the contractor's probability of mission success is increased, but the probability of crew safety is lowered. These differences in abort ground rules are scheduled for resolution by the Spacecraft Reliability Analysis Program Management Panel.

The ranking by unreliability contribution of the individual subsystems with the environmental control system is: Water-Glycol Circuit, Pressure and Temperature Control, Water Supply, and Oxygen Supply. These systems account for 99 percent of the environmental control system unreliability.

The Water-Glycol Circuit and the Pressure Suit Circuit are the greatest contributors to unreliability of the system (47 percent and 23 percent, respectively). The complexity of these two loops is greater than that of the other three. The Water-Glycol and Pressure Suit Circuits also contain the greatest number of critical components. Figure C.5-8 shows the most critical components within the system loops, cites associated major problems, and gives comments.

(*) Crew safety probability estimate for the environmental control system is based on the assumption that all other subsystems interfacing with the environmental control system, e.g., the oxygen supply system, are functioning as intended.

[redacted]

Subsystem/Component	Major Problem Area	Comments
Water Glycol Circuit		
Water-glycol pump assembly	Bearing life-alternating current motor bearings	Design improvements for bearing seals are being implemented.
Water-glycol evaporator control	Back pressure and wetness controls are non-redundant	Evaporative type heat exchanger requires complex electronic control mechanism in comparison to sublimative type heat exchanger as used in the Lunar Excursion Module.
Space radiator and associated control valves	Radiator and water-glycol inflow and afterflow controls	Currently in acceptance test stage.
Pressure Suit Circuit		
Water separator pump assembly	Complexity of cycling device in pump assembly	None
Suit compressor	Bearing life-alternating current motor	Design improvement for bearing seals are being implemented.
Carbon dioxide partial pressure sensor	Complexity of CO_2 sensors (spectroscope type)	A study is recommended to determine feasibility of a back-up for this component such as a color changing indicator device, e.g., acid sensitive litmus paper which could be functioning in parallel with the CO_2 spectroscopic sensor.
Lithium hydroxide cartridge	Cartridge may burst and expel lithium hydroxide powder into pressure suit circuit	A study on the toxidity of lithium hydroxide powder is recommended.

Figure C.5-8. Command and Service Module Environmental Control System Problem Areas and Comments

[redacted]

Subsystem/Component	Major Problem Area	Comments
Pressure and Temperature Control		
CSM cabin recirculating blowers	Bearing life-alternating current motor	Design improvements for bearing seals are being implemented.
Water Supply		
Potable and waste water tanks	Positive explosion bladder mechanism	None
Oxygen Supply		
Regulator and relief valve	Complexity of design configurations	Tests are currently being performed as part of the investigation of this problem.

Figure C.5-8. Command and Service Module Environmental Control System Problem Areas and Comments (Cont.)

C.5.4.3 <u>Command Service Module - Communication</u>

C.5.4.3.1 System Configuration

Contractor (North American Aviation, Inc.) system configuration and engineering data contained in the references 52 and 55 were used for this analysis. There is little apparent difference in generic terminology and functions between Block I and Block II configurations of the communication system. However, the significant Block II change of providing prime guidance and navigation data from ground based (MSFN)* stations instead of from on-board computations, has resulted in major equipment-design modifications in order to improve the resliability and flexibility of the original Block I design. This redesign will compensate for the increased functional importance of the communications subsystem and its interface with the guidance and navigation system.

C.5.4.3.2 Analysis Data

Contractor reliability logic diagrams for the Block II configurations are currently unavailable. Block I communications was, heretofore, treated by the contractor as an independent subsystem, whereas Block II communications is included under Integrated Electronics subsystem. Therefore, for the present analysis, Block I logic diagrams were adapted to Block II requirements as defined in the Design Reference Mission documents (Reference 2). Contractor Block II equipment failure rate data have not been reported. Block I failure rate data was used for this analysis. This data is considered a reasonable approximation. Because of lack of contractor documented equipment operating times, the time data was derived from the Design Reference Mission Documents for use in the Apollo Program Office computations. Considerable uncertainty exists about the appropriate action to be taken (continuation or abort of the mission) in the event of Communication System malfunction. Block II Failure Modes Effects Analyses are currently only 10 percent complete (Reference 38).

In the absence of a definitive source of mission ground rules the following assumptions were used for this analysis:

(1) Loss of any of the major communications functions of voice, tracking, telemetry, or updata capability during the translunar phases of

(*) Manned Space Flight Network

the flight would be cause for mission abort. Emergency voice or key would not be used to continue the mission.

(2) No communication failure is considered to be a fatal failure. Although a number of hypothetical situations can be visualized in which communications failure might be justifiably considered the cause of a fatal failure, these situations are not yet amenable to quantitative evaluation.

(3) Communications failure does not preclude the ability to abort nor impair the probability of safe abort. Although it would be highly desirable to have communications during any abort mode, it is not clearly established whether communication is actually required. It is assumed that emergency voice and key operation is sufficient to support abort modes.

C.5.4.3.3 Results and Conclusions

The overall probability of system success for the Communications System is 0.9696. This system contributed 11.8 percent of the total unreliability of the Command Service Module. The contractor does not provide a Block II communications system reliability estimate but includes it within the Integrated Electronics reliability estimate. The majority of system failures, if any, are expected to occur during the 62-hour interval between translunar injection and lunar orbit insertion. Unreliability appears to be uniformly distributed across all functional areas and is attributable to long operating times. In event of primary equipment failure, emergency backup capability is not used to continue the mission. The greatest cause for the relatively high system unreliability, when viewed against the good communications operational experience of other space missions, is the greater number of functions to be evaluated and the difficulty of accounting for all the potential combinations of acceptable, though degraded, communications system conditions. Based on past spacecraft communications performance, the Block II system configuration can be expected to achieve a higher degree of reliability than currently estimated. The key factor which will help achieve this high reliability is an opportunity for flight verification. This will help resolve anomalies in antenna radiation patterns and MSFN operational procedures which should become apparent in actual performance. Two equipment items which can limit a high level of communications performance are the S-band directional antenna and the S-band power amplifier. Redundancy is provided in the power amplifier section, and a parallel development in the type of tube to be used is expected to increase reliability. Contractor predicted mission reliability is grouped under the general title of Integrated Electronics, therefore no comparison with Apollo Program Office prediction can be made at this time.

C.5.5.5 Service Module - Service Propulsion System (SPS)

C.5.4.4.1 System Configuration

The Service Propulsion System configuration used in this analysis is based upon information derived from a contractor (North American Aviation, Inc.) study guide course given in 1965 (Reference 40) and from contractor quarterly reliability status reports.

C.5.4.4.2 Analysis Data

A model from the contractor's eleventh quarterly report (Reference 47) was used to reflect the most recent configuration changes. An assumption made in model construction was that the Service Propulsion System is the only propulsion available for returning to earth from a translunar or lunar vicinity abort. The equipment timeline profiles used were derived from Apollo Mission Planning Task Force document dated 30 October 1964 (Reference 2). The data used included those given in the contractor's fourth quarterly reliability status report (Reference 48) and data from the Apollo Program Office data bank.

C.5.4.4.3 Results and Conclusions

The system success estimate for the Service Propulsion System is 0.97175. This system contributes approximately 11 percent of the total unreliability attributable to the Command Service Module and 4.5 percent of that attributable to the total Space Vehicle. Service Propulsion System critical components are: the propellant tanks, pressure transducer, helium tanks, and engine assembly (listed in descending order of unreliability). The tanks and transducer criticalities are due to their operation over the full mission time. High failure rates are associated with the engine assembly, which includes the injector, thrust chamber, and nozzle. The high failure rates reflect combustion instability problems associated with the injector and also the erosion problems associated with the thrust chamber. Contractor prediction is 0.9966 (Reference 38). The Apollo Program Office prediction is 0.9717.

C.5.4.5 Service Module - Reaction Control System

C.5.4.5.1 System Configuration

The Command Service Module Reaction Control System configuration used in this analysis is based upon information derived from North American Aviation, Inc. study guide course given in 1965 (Reference 40) and contractor quarterly reliability status reports.

C.5.4.5.2 Analysis Data

A contractor model was derived from Reference 40 and supplemented with recent configuration changes indicated in Reference 47.

The ground rules used in model construction were as follows:

(1) All Reaction Control System quads* are required to be operative from launch through LEM transposition docking (major mission phases: earth ascent to initial translunar coast).

(2) Three of the four Reaction Control System quads are required to be operative from LEM transposition docking (initial translunar coast) through transearth injection.

(3) Any two of the four Reaction Control System quads are required to be operative from transearth injection through service module separation (Transearth Coast).

(4) Any two of the four Reaction Control System quads are required to be operative on an abort path.

The equipment operational timeline profiles used were derived from Design Reference Mission documents dated 30 October 1964 (Reference 2). The data used included those

*Quads (modules): each quad or module incorporates four pulse modulated liquid bi-propellant pressure-fed rocket engines and its propellant feed system - each mechanically independent, located at 90-degree intervals about the service module.

given in the contractor's fourth quarterly reliability status report (Reference 48) and from the Apollo Program Office data bank.

C.5.4.5.3 Results and Conclusions

The probability of system success for the Service Module Reaction Control System is 0.985. This system contributes 5.7 percent of the total unreliability attributable to the Command Service Module and 2.3 percent of the total Space Vehicle mission unreliability. The most critical Command Service Module Reaction Control System components are: the expulsion bladder, propellant quantity sensors, and the isolation shut-off valve. Of these the expulsion bladder problem is considered to be the most serious one.

The crux of the problem at present is the compromise which attempts to make the bladders thick enough to prevent excessive diffusion, which could cause upstream diffusion and subsequent mixing of propellants leading to a possible explosion, and attempts to make the bladders thin enough to prevent cracking due to brittleness. The diffusion problem, along with the requirements for check valves, could be eliminated by feeding oxidizer and fuel from separate pressurization systems. This need not require additional helium tanks and regulators because oxidizer expulsion pressure for 2 quads can be furnished by one pressurization system as easily as fuel and oxidizer pressurization can be furnished from a single system. Extra plumbing would be required, however, and the problem of temperature control for propellants would be aggravated. Even so, a considerable improvement in total reliability might be achieveable in this way with little or no weight penalty.

The contractor reliability prediction is 0.998.

C.5.4.6 Command Service Module-Electrical Power System

C.5.4.6.1 System Configuration

The Electrical Power System configuration used in this analysis was based on the Block I configuration due to current unavailability of Block II documentation. However, indications are that the Block II configuration will be almost identical to that of Block I.

C.5.4.6.2 Analysis Data

The latest available reliability logic diagrams and failure rates published by the contractor (North American Aviation, Inc.) for the Command Service Module Electrical Power System are contained in Reference 36. Some of the failure rates are modified in Reference 37. These logic diagrams and data were used for the present estimate, even though they represent a Block I design. The contractor published logic diagrams have several omissions, which if considered, would lower the present reliability estimate.

(1) The battery charger, which represents a single point failure throughout most of the mission, does not appear in the logic diagrams.

(2) The battery relay bus, which also represents a single point failure under certain conditions, does not appear in the logic diagram. Since this bus has a very low failure rate, the estimate will not be greatly affected.

(3) The two pyrotechnic sequencing batteries, either of which will cause an abort enabling failure, do not appear in the logic diagram.

(4) The two pyrotechnic separation batteries do not appear in the logic diagram. Indications are that these batteries will be eliminated from the Command Service Module Electrical Power System in the Block II design.

Several Block II Design changes which will affect the reliability estimates are outlined below:

(1) Expected elimination of the pyrotechnic separation batteries as mentioned above.

(2) Redesign of the present high acoustical noise static inverters used in Block I, to obtain a low noise Block II static inverter. This redesign will probably cause a different failure rate for the static inverters due to added components (Reference 38).

(3) Replacement of the 25 ampere-hour Entry and Post-Landing Batteries by 40-ampere hour batteries. This change will probably cause a different failure rate for the batteries and will lessen the criticality of the battery charger (Reference 38.)

While continuous operation is required for most components of the Command Service Module Electrical Power System, this is not true for the static inverters. The normal operating mode for the inverters requires that inverter No. 1 and No. 2 operate during the boost phases of launch and during each ΔV maneuver. Only inverter No. 1 operates at all other times. Should inverter No. 1 fail, inverter No. 2 begins continuous operation. Should inverter No. 2 also fail, the mission is aborted and inverter No. 3 is used. While only one inverter operates throughout the majority of the mission, the non-operating inverters are also subject to failure in the standby mode. Because of lack of Block II documentation, comparison of the present Apollo Program Office prediction with that of the contractor would be meaningless at this time.

C.5.4.6.3 Results and Conclusions

A comparison of the predictions for the CSM Electrical Power System (Reference 38) to the present reliability estimate is as follows: The Contractor prediction for system success probability is 0.9959139 while the Apollo Program Office Estimate of system success probability is 0.98174.

Equipment criticality ranking within the Command Service Module Electrical Power System is as follows: Universal Inverter, Direct Current Bus and Distribution, Fuel Cell Subsystem, Alternating Current Bus and Distribution, other Components.

C.5.4.7 Command Service Module - Miscellaneous

To simplify the reliability model, seven systems were combined and an overall reliability value was calculated for use in the simulation model computations. The numerical results obtained were not significantly affected due to the low contribution to mission unreliability of this combination of systems. Only contractor fixed-point reliability values were available for this system combination. This system category includes the following: Structures, Heat Shield, Separation, Emergency Detector, Launch Escape, and Earth Landing Systems.

The relative contribution of the composite of the above systems to the Command Service Module unreliability is 0.86 percent and to the unreliability of the total space vehicle, 0.35 percent.

C.5.4.7.1 Structures

The only available contractor information on the Command Service Module Structures was a reliability value given in Reference 38. The mission success and crew safety apportionments and predictions as called out in the above document are all 0.999999. This value was used in a single block model applied in the beginning of the Earth Orbit phase (when max Q occurs).

C.5.4.7.2 Emergency Detection System (EDS)

At the time of input to this analysis, contractor reliability information on the Emergency Detection System was limited to a single reliability value reported in Reference 38. This value was used with a single block representing the system in the simulation model. The contractor prediction of system success probability is 0.9999910 and for crew safety probability it is 0.9999990.

The above reliability values are interpreted as follows. Since the Emergency Detection System performs only a monitoring function during a successful boost, the mission success value of the EDS is the probability of not causing a false abort. The crew safety number then would be the probability of the EDS initiating an abort should an abort be required.

There have been questions concerning a "hot" versus "cold wire" design philosophy. In the "hot wire" design, an Emergency Detection System power failure would cause an immediate mission abort. In the "cold wire" design, an Emergency Detection System power failure would not cause an abort and, in fact, could preclude an Emergency Detection System abort, although aborts via the translation controller would still be possible. This issue is quite basic to the mission concept because the Emergency Detection System is required only during the boost phase and is in the automatic mode during first stage boost only. Once the boost phase is finished, the Emergency Detection System is not required, so an abort due to an Emergency Detection System power failure is technically a "false abort." On the other hand, an automatic Emergency Detection System abort is the only "safe abort" mode during first stage boost due to time constraints, so that continuation without the EDS capability involves increased crew risk.

C.5.4.7.3 Launch Escape System (LES)

North American Aviation Block I models and numbers, as extracted from Reference 39, were used for this analysis. The models do not include the sequencing required by the Launch Escape System nor the canard deployment for Launch Escape System aborts. In the process of simplification, the model was reduced and a fixed point reliability number calculated for input to the mission model. This fixed point number is 0.999984 and is applied in both the mission success and abort configurations.

The qualification test of the fourteenth tower jettison motor showed an ignition delay of 2.5 milliseconds. The problem is presently under investigation (Reference 38).

C.5.4.7.4 Earth Landing System (ELS)

The reliability logic diagrams were extracted from Reference 38 and the reliability values from Reference 8. The contractor (North American Aviation, Inc.) did not have supporting numbers for every block called out in the logic diagram, so applicable values from the Apollo Program Office data bank were used. The model included all parts of the Earth Landing System and is detailed to the switch and relay level, with failure modes included. For simplification purposes, a reduction was accomplished and two fixed-point reliabilities calculated; one applied to the forward heat shield deployment and the other to drogue chute deployment.

C.5.4.7.5 Heat Shield

The only contractor reliability information available on the heat shield is the fixed point reliability estimate extracted from Reference 38 and used as input to this analysis. Contractor prediction of system success probability is 0.999960 and of crew safety probability, 0.999960.

The unreliability caused by the heat shield was assumed to occur during the re-entry subphase. Demonstration of heat shield performance is presently scheduled for the Apollo-Saturn 201 Mission.

C.5.4.7.6 Separation System

The major functional blocks of the Command Service Module Separation System are Service Module/LEM Adapter Separation, Command Module/Service Module Separation, and Forward Heat Shield Separation. The Block I numbers given for these individual functions in Reference 39 do not agree with the top level Block II numbers given in Reference 38. The contractor predicted top level Block II reliability values used for the present estimate of system success probability and crew safety probability are 0.9999715 and 0.999770, respectively. For the purposes of this study, it was assumed that the Separation System could fail only during those mission intervals where a separation function is required.

C.5.4.8 <u>Command Module-Reaction Control System (RCS)</u>

C.5.4.8.1 System Configuration

The Command Module Reaction Control System configuration considered in this analysis is based upon information derived from a North American Aviation, Inc. study guide course given in 1965 (Reference 40) and contractor quarterly reliability status reports.

C.5.4.8.2 Analysis Data

No up-to-date contractor models for the Command Module Reaction Control System were available at the time of this analysis. Logic diagrams were developed from information sources cited in the preceding paragraph. The diagrams reflect the Design Reference Mission as indicated in the Apollo Mission Planning Task Force documentation (Reference 2).

Ground rules used for model construction were as follows:

(1) Since the Command Module Reaction Control System is required for re-entry, it was assumed that both system A and B* are required up to the period of jettisoning the Lunar Excursion Module.

*The Command Module Reaction Control System consists of two identical and independent systems identified as system A and system B. The major components in each system are the pressurization system, propellant supply and distribution system, six rocket engines and a propellant jettison system.

(2) On the return trip, system A and B are redundant since only one is required for re-entry.

(3) A minimum of five (5) engines are required to exhaust the remaining hypergolic propellant during parachute deployment prior to touchdown. This could be accomplished by using system A or B helium supplies for pressurization of the fuel.

(4) Purging of this remaining fuel can be accomplished with either system A or system B helium supply.

C.5.4.8.3 Results and Conclusions

The probability of system success for the Command Module Reaction Control System is 0.99845. This system contributes 0.6 percent of the unreliability attributable to the Command Service Module. Critical components in the Command Module Reaction Control System are the helium tank, and the pressure and temperature transducers. The expulsion bladder does not appear to be as much a problem in the Command Module system as it is in the Service Module because the Command Module Reaction Control System operating time is considerably less. However, the bladder diffusion problem described in paragraph C.5.4.5.3 pertains to its use in the Command Module Reaction Control System regardless of the low operating time. The helium tank and transducer of this system also accumulate the full operational mission time, and this also contributes to unreliability. There is no appreciable difference between the Apollo Program Office prediction and that of the contractor.

C.5.4.9 <u>Command Service Module - Cryogenic Storage</u>

C.5.4.9.1 System Configuration

System configuration as reflected in the contractor's sixth quarterly report (Reference 52) was used for this analysis.

C.5.4.9.2 Analysis Data

Logic diagrams and reliability data as contained in the contractor's sixth quarterly report (Reference 52) were used exclusively. However, the contractor's prediction is based upon data and models which are now out of date.

C.5.4.9.3 Results and Conclusions

The probabilities of system success for the Command Service Module Cryogenic Storage is 0.997. The most critical components in the Command Service Module Cryogenic Storage are the pressure transducer and the quantity probe and indicating device (quantity gauging of supercritical cryogenic fuel in zero gravity requires complex equipment).

C. 5.5 LUNAR EXCURSION MODULE

The Lunar Excursion Module contribution of 31 percent of the Spacecraft unreliability is due to the following systems (See Figure C. 5-9): Electrical Power System (37 percent); Communications (22 percent); Environmental Control System (16. 6 percent); Guidance and Control (11 percent); Reaction Control System (10. 7 percent) and the combination of Structures, Ascent Propulsion, Descent Propulsion and Pyrotechnics (2. 7 percent).

Figure C. 5-10 and Figure C. 5-11 depict the current mission success and crew safety reliability apportionments and estimates of the LEM systems, as reported by the contractor. In addition, Figure C. 5-10 contains a column which presents the Apollo Program Office prediction estimates.

A more detailed analysis of the results of this study and comparisons of these results with contractor estimates as they pertain to the Lunar Excursion Module systems are given in paragraphs C.5.2.1 through C.5.2.6.

C.5.5.1 Lunar Excursion Module - Electrical Power System

C.5.5.1.1 System Configuration

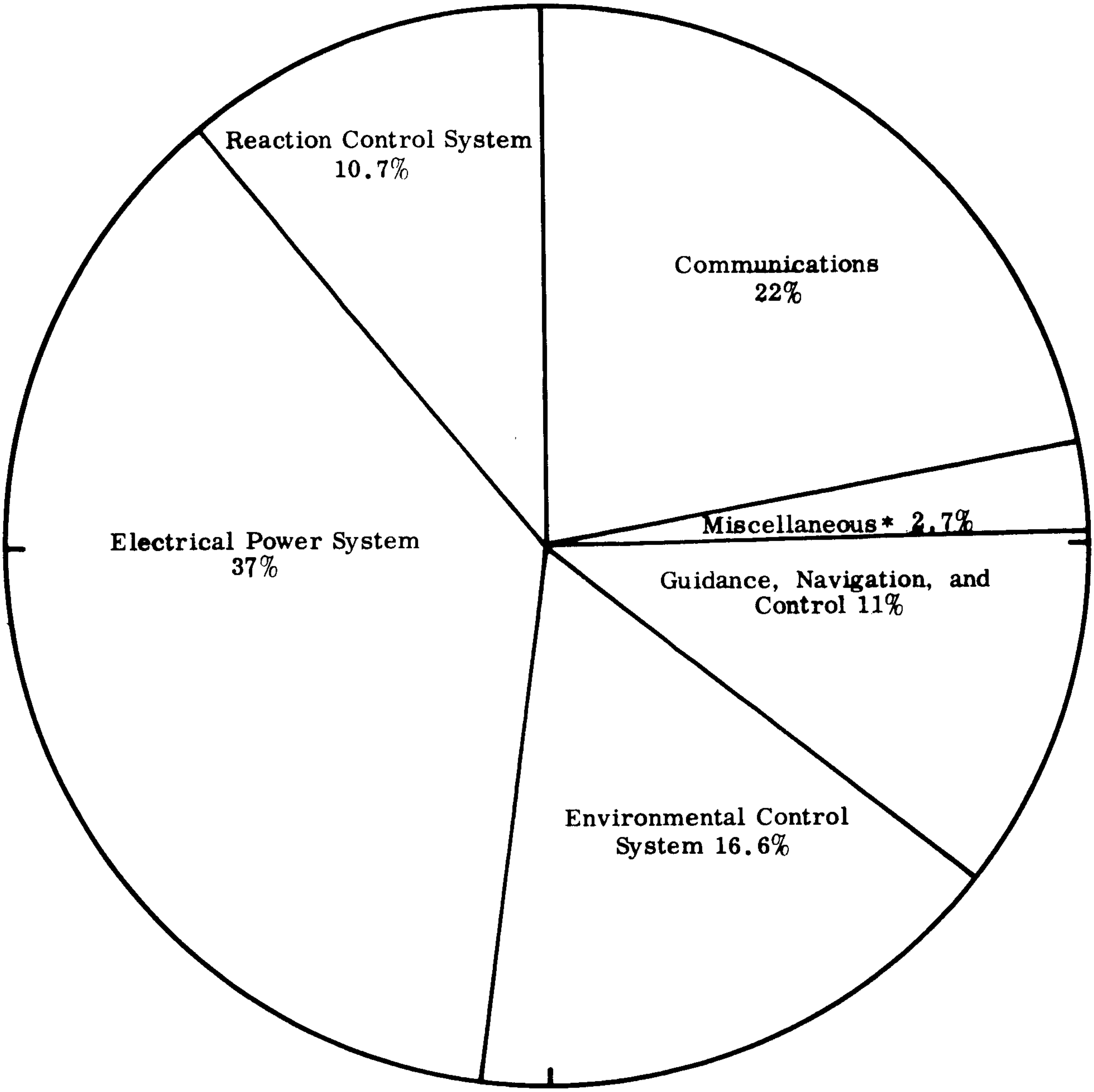
The Electrical Power System configuration used in this analysis is based on the latest data about major elements of the system. The configuration includes four descent batteries, two ascent batteries, two inverters, and redundant distribution elements. A power interface is provided with the Command Service Module from which the LEM receives necessary primary power prior to LEM checkout during translunar coast.

C.5.5.1.2 Analysis Data

The reliability logic diagrams upon which the estimate of LEM Electrical Power System unreliability is based consist essentially of two equipment configurations. The first is applicable to mission success from earth liftoff to lunar liftoff and is essentially a reliability series configuration of all the power system elements. The power system has only two combinations of equipments capable of providing the system functional

APOLLO SATURN 504 MANNED LUNAR LANDING MISSION

Lunar Excursion Module



***Miscellaneous includes structure, ascent propulsion, descent propulsion, and pryotechnics.**

Note: 1. The Lunar Excursion Module accounts for 18.4 percent of space vehicle unreliability.

2. Ground Operational Support System and crew functions were considered to have a reliability of 1.0 for this study.

Figure C.5-9. Percentage Contribution of Systems to Lunar Excursion Module Unreliability

[redacted]

System	Mission Success Reliability Apportionment*	Ref.	Mission Success Reliability Prediction*	Ref.	Difference: Apportionment Minus Prediction	Apollo Program Office System Success Probability Estimate
Navigation and Guidance and Stabilization and Control	0.9907	42	0.988205	42	+0.002495	0.98725
Descent Propulsion	0.999075	42	0.998764	42	+0.00311	0.9969
Ascent Propulsion	0.999961	42	0.99830	42	+0.00166	0.9969
Reaction Control System	0.999804	42	0.944117	42	+0.055687	0.98761
Electrical Power System	0.99860	42	0.963896	42	+0.03470	0.95723
Environmental Control System	0.999446	42	0.988865	42	+0.01058	0.98079
Communications	0.99991	42	0.99768 (with EVA)**	42	+0.00223	0.98818 (without EVA)** 0.97462 (with EVA)**
Instrumentation and Displays	0.99950	42	0.999378	42	+0.00012	
Structures	0.99995	42	0.999978	42	+0.000028	0.999999
Pyrotechnic	0.99998	42	0.999924	42	+0.000056	0.999999
Overall Lunar Excursion Module	0.987/0.984	42/55	0.884	42	+0.103	0.88942

* Data is current only up to and including 1 May 1965 contractor's eighth quarterly report (Reference 42).

**EVA: Extra-Vehicular Activity (See par. C.5.5.2.3).

Figure C.5-10. Lunar Excursion Module Mission Success Reliability Apportionments, Predictions, and Comparisons

[redacted]

[redacted]

System	Crew Safety Reliability Apportionment*	Ref.	Crew Safety Reliability Prediction*	Ref.	Difference: Apportionment minus Prediction
Navigation and Guidance and Stabilization and Control and Communications	0.999875	45	0.99651	42	+0.003365
Descent Propulsion	0.999998	45	0.999399**	42	
Ascent Propulsion	0.999976	45			
Reaction Control System	0.999935	45	0.999274	42	+0.00066
Electrical Power System	0.999916	45	0.999993	42	-0.000077
Environmental Control System	0.99982	45	0.998896	42	+0.00092
Instrumentation	***	45	***		***
Structures	0.99998	45	0.999999	42	-0.000019
Pyrotechnic	0.99998	45	0.999954	42	+0.000026
Overall Lunar Excursion Module	0.9995/0.9995	45/55	0.99717	42	+0.00233

* Data is current only up to and including 1 November 1964 (Ref. 45).

** Includes both Descent and Ascent Propulsion.

***Not applicable to crew safety.

Figure C.5-11. Lunar Excursion Module Crew Safety Reliability Apportionments, Predictions, and Comparisons

[redacted]

requirements. As a result, if one combination or (path) fails, the next failure could result in crew loss.

The second configuration applies from lunar liftoff to LEM jettison and is a redundant configuration with all possible success paths included. The second configuration is representative of mission success paths from lunar liftoff to LEM jettison or to any abort attempt. The reason for the series configuration is due to the fact that the power system has two redundant paths and if one path should fail, the next failure would be fatal.

C.5.5.1.3 Results and Conclusions

The predicted probability of Electrical Power System success is 0.95723. This system contributes 37 percent of the mission unreliability attributed to the LEM. This also represents 6.4 percent of the unreliability for the total Space Vehicle over the entire Manned Lunar Landing Mission.

The large impact of the Electrical Power System on LEM mission success is due almost entirely to the rather stringent ground rule that all four descent batteries must operate during lunar stay and that mission success include a 34.7-hour stay. The four descent and two ascent batteries contribute 70 percent of the Electrical Power System unreliability. In this instance, unreconciled data and models contributed to the small difference between the Apollo Program Office reliability prediction of 0.9572 and the contractor's reliability prediction of 0.9639.

Some concern has been voiced because of predicted overheating of an ascent battery should one ascent battery fail returning from the lunar surface. This is primarily due to load requirements and the present limitations of the Environmental Control System's water-glycol cooling loop. It is understood that a redesign is underway to provide more coolant flow through the battery cold plates and that this may alleviate the overheating problem.

C.5.5.2 <u>LEM Communications</u>

C.5.5.2.1 System Configuration

Two conflicting Communications System configurations are presented in contractor (Grumman) documentation. One configuration is contained in the Communications System Specification (Reference 53) whereas another configuration is recommended on the basis of the Design Reference Mission studies (Reference 54). The configuration recommended in Reference 54 was used for this analysis.

C.5.5.2.2 Analysis Data

Logic diagrams and failure rate data were obtained from the contractor's first seven quarterly reliability reports. Some modifications of available contractor models were required in order to reflect the Design Reference Mission configuration.

Conflicts were noted in the contractor's system ground rules with respect to Communications. Used for this analysis were the more stringent ground rules supplied by the contractor's communications group. These ground rules define VHF, S-band, EVA and signal conditioning equipment as necessary system functions to achieve mission success. Additional ground rules used were as follows:

(1) No communication failure is fatal to the crew.

(2) Emergency voice or key does not serve as a backup prior to lunar landing.

C.5.5.2.3 Results and Conclusions

The probability of system success for the Communications System estimated by the Apollo Program Office is 0.9746. This contributes 22 percent of the unreliability of the Lunar Excursion Module. The prime cause of this high system unreliability is the EVA backpack transceiver, for which early failure rate data reported by a contractor (Reference 41) was the only data furnished. The contractor's system success probability estimate <u>without</u> EVA backpack transceiver, is 0.99768 (Reference 42).

Excluding the EVA from considerations, the Lunar Excursion Module communications reliability estimate is 0.98818. The failure rate associated with the transceiver should be investigated. Since the transceiver failure rate data is questionable and, since each transceiver has two transmitters and two receivers, the potential for high reliability is indicated. However, the early failure rate data indicate problems with EVA transceiver which account for the difference between the contractor's reliability prediction and that of the Apollo Program Office.

Except for the EVA transceiver there are no serious reliability problems in the LEM Communication System. However, the S-band power tube and erectable antenna require continued attention in the test phases to establish assurance of the reliability of these components.

Previous spacecraft communications experience indicates that the system configuration as recommended in the Design Reference Mission document has the potential of providing acceptable communications performance.

C.5.5.3 Lunar Excursion Module - Environmental Control System (ECS)

C.5.5.3.1 System Configuration

Used for this analysis was the Grumman Aircraft and Engineering Corporation configuration of the Environmental Control System for LEM 4 as described by the system schematic diagram (Reference 43).

C.5.5.3.2 Analysis Data

The calculations are based on reliability logic diagrams derived from contractor data (Reference 43). These diagrams and associated failure rates supplied by the contractor were reviewed for validity at a Spacecraft Reliability Analysis Program Data review meeting held on 21-23 June 1965 (Reference 49). The equipment timeline profiles were derived from the Design Reference Mission (Reference 2).

The reliability logic diagram of the LEM Environmental Control System contained the ground rule that the portable life support system can serve as backup to the entire Environmental Control System if an abort involving the Lunar Excursion Module is initiated after "LEM-CSM separation."

C.5.5.3.3 Results and Conclusions

The probabilities of system success for the LEM Environmental Control System are 0.981. The inconsistencies in models and abort ground rules, noted under the CSM Environmental Control System, also apply to the LEM. These differences are scheduled for resolution by the MSC Spacecraft Reliability Analysis Program Management Panel and Data Review Meetings.

The most critical components within the Environmental Control System are the Water-Glycol Pumps, the Pressure Suit Compressor, and the Cabin Recirculating Blower. Low reliability of the brushless DC motors in these components is the common problem area. The major problem areas and comments on these components are tabulated in Figure C.5-12. Reliability predictions by the Apollo Program Office and the contractor are in close agreement.

C.5.5.4 <u>Lunar Excursion Module - Guidance and Control</u>

C.5.5.4.1 System Configuration

The system configuration was developed using minutes from LEM Guidance and Control implementation meetings and contractors' reports. The Guidance and Control configuration establishes the Massachusetts Institute of Technology/AC Spark Plug Guidance System as the primary LEM control. The Grumman furnished Stabilization and Control System becomes an independent abort backup system. Both systems have manual control capabilities.

C.5.5.4.2 Analysis Data

The Guidance and Control reliability logic diagrams used for this analysis are based on the Apollo Mission Planning Task Force Design Reference Mission documents

[redacted]

APOLLO-SATURN 504 MANNED LUNAR LANDING MISSION

System/Component Subsystem	Major Problem Areas	Comments
Atmosphere Revitalization Section		
1. Lithium Hydroxide Cartridge	Cartridge may burst and expel lithium hydroxide powder into pressure suit loop.	A study on the toxicity of lithium hydroxide powder is recommended.
2. LEM Cabin Recirculatory Blower	Bearing life in direct current motor; complexity and commutation problems of direct current motor design.	The test program has so far not produced satisfactory DC motor reliability. NASA-MSC has initiated stringent testing procedures to be implemented by the contractor.
3. Pressure Suit Compressor	(Same as Preceding Entry.)	(Same as Preceding Entry.)
Thermal Control System		
1. Water Glycol Pumps	(Same as Preceding Entry.)	(Same as Preceding Entry.)

Figure C.5-12. Lunar Excursion Module Environmental Control System Problem Areas and Comments

[redacted]

(Reference 2). The failure rates for LEM Guidance and Navigation were obtained from MIT data (Reference 33). The Stabilization and Control information was obtained from contractor data (Reference 44). Equipment failures during non-operating periods were not considered for this analysis.

Equipment checkout and updating, using Command Service Module reference data, requires approximately two hours before LEM separation. Mission success criteria require the equipment to operate during this time period. Crew safety is not a factor because the mission will be aborted before LEM separation if a failure is detected.

C.5.5.4.3 Results and Conclusions

The probability of system success for LEM Guidance and Control is 0.98725. This is based on the mission ground rule that all equipment essential to mission success must operate after LEM separation, and for a minimum of 4 hours after touchdown on the lunar surface. After the lunar exploration phase, redundant equipment configurations are used with the backup guidance system as an alternate mode. For this analysis, the LEM is required to operate through docking, although the Command Service Module is capable of a rescue if necessary. The redundant configuration with the backup guidance system can be used at any time in the mission when an abort is initiated. Apollo Program Office reliability prediction (0.98725) for this system is in close agreement with that of the contractor. The major portion of the LEM Guidance and Control System unreliability occurs during those mission phases when ground rules preclude the use of redundant equipments for mission continuation.

The individual equipments contributing the most to mission unreliability in descending order are: Abort Sensor Assembly, LEM Guidance Computer, Abort Electronic Assembly, and Rendezvous Radar.

The abort equipment has the lowest equipment reliability due to the grouping of much major equipment in one "black box." The Abort Sensor Assembly contains all the inertial reference equipment, and the Abort Electronic Assembly contains the computer and timing equipment for the backup guidance system.

The LEM Guidance Computer is the control center of the Guidance and Navigation System. The complexity of this equipment and demanding program requirements contribute to its unreliability rating. A study is being made to determine the feasibility of replacing the Rendezvous Radar system with an Optical Track system, because the reliability estimate for the Rendezvous Radar does not meet the apportioned reliability.

C.5.5.5 Lunar Excursion Module Reaction Control System

C.5.5.5.1 System Configuration

The Reaction Control System is represented as described in the contractor's (Grumman) Seventh Quarterly Report (Reference 45).

C.5.5.5.2 Analysis Data

Used for this analysis were contractor reliability estimates, total operating time, and stress modification factors, as reported in Grumman's Seventh Quarterly Report. (Reference 45)

C.5.5.5.3 Results and Conclusions

As reported in the contractor's eighth quarterly report, a Design Reference Mission Profile change has significantly affected the reliability of this system. The change requires the Reaction Control System to remain pressurized during 34.7 hours lunar stay rather than a four-hour stay (Reference 42). This change in the mission profile creates a reliability problem because all of the 32 thruster valve assemblies are required to function during the lunar stay period. This requirement accounts for 80 percent of the Reaction Control System unreliability. The valves fail primarily because of leakage. Fuel system contamination at the thruster valves and a high duty cycle count may prevent the valves from seating correctly. The contractor states in his eighth quarterly report that better detection of injector valve failures will improve abort capability. It is also reported that the present bladder leakage and ruptures will be eliminated if a 6-mil, single-ply bladder is used in place of the 3-mil, 3-ply bladder.

The Apollo Program Office reliability prediction for the LEM Reaction Control System is 0.9876. The contractor prediction is 0.9441. The difference is largely accounted for by the use of models which do not reflect current, revised ground rules.

C.5.5.6 Lunar Excursion Module - Miscellaneous Systems

Miscellaneous systems include LEM Structures, Ascent Propulsion, Descent Propulsion, and pyrotechnics. These systems were grouped under a common heading only because most of the systems had a fixed reliability value for each subphase in the mission. The percentage of LEM unreliability attributed to these systems is 2.64 percent and the percentage of mission unreliability is 0.49 percent.

C.5.5.6.1 LEM Pyrotechnic System

The latest available reliability information on the pyrotechnic system was the top level Block II prediction data from Reference 42. The contractor prediction of system success probability is 0.999924 and the crew safety probability is 0.999. In Reference 42 the contractor's apportioned and predicted mission success reliabilities are .99998 and .999924 respectively. A crew safety apportionment of .99998 is contained in Reference 45 and a prediction in Reference 42 of .999954. With the high reliabilities involved, these differences have little effect on mission and LEM system reliability. These predictions are in complete accord with those of the Apollo Program Office.

Nearly all of the Pyrotechnics are required only during the subphase in which the system engineer re-enters the LEM (Subphase 51). In the present analysis all Pyrotechnic failures were assumed to occur during Lunar Prelaunch Checkout interval.

C.5.5.6.2 LEM Structures

Available reliability information used for analysis of the LEM Structures is the top level Block II prediction data contained in Reference 46, as follows: mission success probability is 0.999999 and the crew safety probability is 0.999999. Reference 42 specified apportioned mission success and predicted mission success and crew safety respectively as 0.99995, 0.999978, and 0.999999. The apportioned crew safety in

Reference 45 is 0.99998. With the high reliabilities involved, these differences have little effect on mission and LEM system reliability.

C.5.5.6.3 LEM Descent Propulsion System

The system configuration considered represents the LEM Descent Propulsion System as described in the contractor's (Grumman) seventh quarterly report (Reference 45).

C.5.5.6.4 Analysis Data

Reliability estimates, total operating time, as reported in the contractor's seventh quarterly report (Reference 45) were used for this analysis.

C.5.5.6.5 Results and Conclusions

The current system success probability estimate of 0.9969 compares well with the Grumman estimate of 0.9988. The small difference is attributed to three items (1) a shorter translunar flight time used in Grumman's model because of slight variations in calculated mission time; (2) use of a more reliable supercritical helium storage in Grumman's model.

The major contributors to unreliability in the Descent Propulsion System are the following: Helium Squib Valve, Helium Latching Valve (solenoid operated). Helium Pressure Relief Valve and Burst Disc Assembly, and the Helium Storage Tank.

The contractor reports that the valve assemblies fail due to leakage resulting from improper valve seating after the valves have been energized. Better filtration and purge techniques are to be incorporated to alleviate the problems.

C.5.5.7 <u>LEM Ascent Propulsion System</u>

C.5.5.7.1 Systems Configuration

The system configuration considered represents the Descent Propulsion system as described in the contractor's (Grumman) seventh quarterly report (Reference 45).

C.5.5.7.2 Analysis Data

Used for this analysis were reliability estimates and total operating time reported in the contractor's seventh quarterly report.

C.5.5.7.3 Results and Conclusions

The current system success probability estimates of 0.9969 compares well with the Grumman estimate of 0.9983. The difference is attributed to two items (1) a shorter translunar flight time used in the contractor's models and (2) the grouping of the Ascent Propulsion System in a "Miscellaneous" category for the present analysis.

The major contributors to system unreliability in the Ascent Propulsion System are the following: Helium Squib Valve, Helium Latching Valve (solenoid operated), Helium Pressure Relief Valve and Burst Disc Assembly, and the Helium Storage Tank.

The contractor reports that the valve assemblies fail due to improper valve seating. Better filtration and purge techniques are being incorporated to alleviate the problem.

C.5.6 CREW SYSTEMS

The current configuration of the Crew Systems were discussed at a recent Manned Space Flight Center Reliability Data Review Meeting. It was tentatively agreed that the Crew System and Crew Provisions should be studied from a Failure Mode Effect Analysis and Configuration viewpoint, before mathematically representing the Crew System elements in reliability logic diagrams. A reliability of 1.0 was assumed for both Crew System and Crew Performance in this analysis.

C.6 GROUND OPERATIONAL SUPPORT SYSTEM (GOSS)

This section conveys the current reliability information on the Apollo Saturn Ground Operational Support System. For the purpose of making computations of crew safety and mission success probabilities in the absence of sufficient reliability data, GOSS functions during the mission are assumed to be performed with a 1.0 reliability.

C.6.1 SYSTEM DESCRIPTION

The Apollo Saturn Ground Operational Support System is an information transportation system supporting the communications and tracking capabilities of the space vehicle. GOSS is composed of complex facilities which will be operated by many and diversified agencies. These facilities will be variably configured for each mission as well as during each mission. GOSS functional support involves the following organizations; NASA, Department of Defense and associated contractors, and the national and international communications carriers.

Apollo Saturn GOSS consists of:

1. Manned Space Flight Network
2. Control Centers
    a. Manned Space Flight Control Center
    b. Launch Control Center
    c. Huntsville Operational Support Center
3. Communications
    a. Space Vehicle to Site
    b. Intra-site
    c. Inter-site
4. Recovery Force (control and communications)

GOSS facilities are located on the ground, in aircraft, in ships, and in communications satellites.

The Manned Space Flight Network includes worldwide facilities of the United States Government and several private agencies, constituting the following subsystems:

1. Voice Communications Subsystem
2. Telemetry Subsystem
3. Tracking Subsystem
4. Digital Command Communications Subsystem
5. Television Subsystem
6. Display and Control Subsystem
7. Data Processing Subsystem
8. Timing Subsystem

C.6.2 SYSTEM SUPPORT COVERAGE

Reference 1 includes charts that specify the mission phases during which each MSFN subsystem is required to perform its functions with respect to the spacecraft, but the Display and Control, Data Processing, and Timing Subsystems are absent from these charts. In general, Launch Vehicle requirements of the Manned Space Flight Network include Telemetry, Tracking, and Digital Command Communications for 6.5 hours following liftoff of the Manned Lunar Landing Mission. The Command Service Module requirements include Voice Communications, Telemetry, Tracking and Digital Command Communications to be carried on throughout the entire mission except during periods of thrusting. Television is specified during earth orbit and translunar coast phases. During operation of the Lunar Excursion Module, Voice Communications, Telemetry and Tracking are required. Television is called for during lunar surface operations. Reference 2 contains the support requirements for GOSS in more detail.

The Manned Space Flight Network functions considered essential to mission success include navigation (redundant to on-board celestial navigation), monitoring (redundant to on-board displays), voice communications (ground personnel redundant to crew for decision-making, trouble-shooting and technical advice).

The Design Reference Mission (Reference 2) states that GOSS support is limited to about one-third of the earth orbit time. This limitation is due to the effect GOSS station location has on antenna coverage. Launches at higher than 72 degree azimuth, either planned or resulting from launch delay, could result in less coverage. Mission events obscured by the moon cannot presently be directly supported by GOSS.

In listing the required Apollo Saturn GOSS facilities, the Design Reference Mission (Reference 2) is currently incomplete. The format shows the GOSS sites acquiring and losing the space vehicle at specified times, but does not specify alternative mission essential functions, such as navigation or monitoring. Updating of the GOSS references for clarification of terminology concerning mission essential functions, is required for reliability studies.

The Block 1 Guidance and Navigation system was designed for on-board navigation, with earth-based tracking as a backup mode. The Block II Guidance, Navigation and Control system to be used on all manned lunar flights will rely on earth-based tracking. The on-board capability is retained, but only as a backup.

Recommended mission ground rules require mission abort when one more failure would result in loss of the crew. Since there are but two means of navigation, loss of either dictates an abort. Accordingly, loss of earth-based tracking capability would constitute mission failure, since the crew would initiate an abort using the on-board capability. Those elements of the ground Operational Support System which are required for tracking the spacecraft, computing required velocity corrections, and transmission of this information to the spacecraft, are deemed critical to the success of all manned Apollo lunar missions. There are circumstances, however, under which the mission probably would continue in spite of loss of GOSS navigation capability. Since ground system failures can usually be repaired quickly, there are segments of the Apollo mission during which transmission of navigation data could be delayed until repairs were accomplished. These segments are the earth and lunar orbits, and the long coasting segments of the translunar and transearth phases. On-board celestial navigation might be used to continue the mission if GOSS navigation were expected to be restored quickly.

C.6.3 CONCLUSIONS AND RECOMMENDATIONS

The overall capability of the Apollo Saturn Manned Space Flight Network to support the Apollo Saturn missions is being reviewed by a group composed of representatives from the NASA Centers and NASA Headquarters (Reference 59). The initial meeting was in January 1965. A joint NASA/DOD group was formed in March 1965 to examine the possibility of single point failure in the Ground Operational Support of Gemini and Apollo (Reference 60). Both groups have isolated potential problems in GOSS operations and are working toward solutions. Comprehensive reliability data is not currently available on Apollo-Saturn GOSS. A need exists for a GOSS reliability analysis, paralleling the operational planning review of the Manned Space Flight Network and the mission, to define the operational requirements for the network, and develop reliability information.

GLOSSARY OF TERMS

Abort Criteria	A stipulation of the conditions of the Apollo System under which the nominal mission will be discontinued and an abort attempted.
Conditional Reliability	The probability that a system, subsystem, component or part will perform its required function under defined conditions at a designated time and for a specific operating period, given that it has operated as intended up to and including a specified time point within the operating period.
Crew Safety	The event that all flight crew members of a given manned space vehicle undertaking a specified flight mission return to earth either via the nominal mission or abort paths without having suffered loss of life due to failures or functional deficiencies of mission associated equipments.
Crew Safety Probability	The likelihood (relative frequency) that the event "Crew Safety" will occur on any <u>one</u> flight mission.
Critical System and/or Equipment List	A ranking of system and/or equipments of the Apollo system in order of their respective fractional contribution to total system unreliability.

Critical Phase List	A ranking of Apollo mission phases in order of their contribution to mission unreliability.
Failure Data	The numerical values associated with Apollo system equipments which specify their failure rate, mean life, or some other numerical reliability parameter.
Functional System	A subsystem or group of subsystems performing a common function, e.g., Guidance and Navigation.
Mission Essential Equipment	Equipment or combination of equipments whose failure precludes successful mission completion.
Mission Phase	An interval of time encompassing a specified sequence of events essential to the execution of a mission.
Mission Success	The event that a flight mission carried out by a given manned space vehicle fully achieves each and every objective specified for the nominal mission.
Mission Success Probability	The likelihood (relative frequency) that any specific mission will achieve all of its assigned objectives.
Percent Contribution to Unreliability	The fraction, expressed as a percentage, which is formed by dividing the unreliability of an equipment by the sum of

unreliabilities of all the equipments in the system under consideration.

Relative Safety Hazard — A normalized index of phase criticality obtained by multiplying the phase unreliability by the probability that an abort taken from this phase will fail, and dividing this product by the unreliability of the most unreliable phase in the mission.

Reliability — The probability that system, subsystem, component, or part will perform its required functions under defined conditions at a designated time and for a specified operating period. This term is also used in a more general sense to signify non-failure. Depending upon context, Reliability and success probability can therefore be numerically equal.

Reliability Data — A generic term denoting a set or sets of quantitative and/or qualitative terms of information pertaining to the intended or actual performance and to reliability in performance of equipments.

System Success Probability — The likelihood (relative frequency) that this system will not cause mission failure.

Unreliability — The probability that a system, subsystem, component or part will not perform its required function under defined conditions at a designated time and for a specified period. (Unreliability is equal to 1.0 minus the reliability).

[redacted]

REFERENCES

1. NASA, Office of Manned Space Flight, Apollo Program Specification (U) May 1965, Confidential.

2. Apollo Mission Planning Task Force, Design Reference Mission, Volume 1, Mission Description, Volume 2, Preflight Sequence of Events, Volume 3, Inflight and Recovery Sequence of Events, 30 October 1964.

3. General Electric Company, Apollo Support Department, Design Reference Mission Reliability Profile (Draft) (U), ASD-MR-05-65-5, Class III, 28 May 1965, Confidential.

4. NASA Office of Manned Space Flight, Apollo Reliability and Quality Assurance Program, Quarterly Status Report (U), Second Quarter 1965, RA 018-001-1, 9 July 1965.

5. Boeing Company, Saturn S-IC Stage Reliability Analysis Record, D5-11954-1, 1 April 1965.

6. Boeing Company, Integrated S-IC System Design Analysis, D5-12572-3, 28 June 1965. (Integrated Single Thread Analysis, 1 July 1965).

7. Boeing Company, Saturn V/S-IC Quarterly Technical Progress and Program Review, 3rd Quarter, Fiscal Year 1965.

8. Rocketdyne, F-1 Engine System Bi-Monthly Progress Letter, TIC24367 31 May 1965.

9. Boeing Company, Saturn S-IC Reliability Status Report, D5-11910, 1 October 1964.

10. NASA, Marshall Space Flight Center, Saturn V Program Development Plan, October 1964.

11. North American Aviation Inc., Saturn Stage S-II Reliability Apportionment Report, Rev. 24, SID 62-1225, 24 April 1963.

12. North American Aviation Inc., Saturn S-II Stage Reliability Prediction Report, SID 62-1369, Reissued 23 October 1964.

13. NASA, Marshall Space Flight Center, J-2 Engine Contract, NAS 8-19.

14. North American Aviation, Inc., S-II Airborne System Reliability Apportionments, SID 62-1225, 28 May 1965.

[redacted]

[redacted]

15. NASA, Marshall Space Flight Center, Launch Vehicle Engines Program Development Plans, September 1964.

16. Rocketdyne, J-2 Engine Quarterly Progress Report, R-2600-2, 28 February 1961.

17. Douglas, Reliability Math Model Saturn V/S-IVB Stage, SM-43610, 15 April 1965.

18. Douglas, Supplement Reliability Mathematical Model, Saturn V/S-IVB Stage, SM-44748, 15 June 1965.

19. NASA, Marshall Space Flight Center, Drawing 20M97008, Rev. A, Sheet 35, 7 January 1965.

20. NASA, Office of Manned Space Flight, Apollo Program Specification (U), SE-005-001, May 1965, Confidential.

21. International Business Machines, Inc., Monthly Progress Report for April 1964, 64-942-02, 20 May 1964.

22. International Business Machines, Inc., Quarterly Technical Review, 27 May 1965.

23. North American Aviation, Inc., Rocketdyne Division, Production of F-1 Engine, Contract NAS 8-5604.

24. Douglas, Saturn S/IVB Program, Contract NAS 7-101.

25. Boeing Company, S-IC Quarterly Technical Progress and Program Review, Fourth Quarter, 28 July 1965.

26. 10th National Symposium on Reliability and Quality Control, Reliability Prediction in Design Decision, John R. Levinson, P&VE, MSFC, 7 January 1964.

27. North American Aviation, Inc., Saturn S-II Ullage Motors Subsystem Report, SID 62-143, Re-issued 26 September 1963.

28. General Electric Company, TEMPO, Engineering Evaluation Planning Study for Large Solid-Propellant Stages - Phase I, #RM62TMP-64, December 1962.

29. Boeing, "Saturn V/S-IC Quarterly Technical Progress and Program Review, 3rd Quarter, Fiscal Year, 1965.

30. North American Aviation, Inc., Reliability Plan, SID 62-203, May 1964.

31. North American Aviation, Inc., Command and Service Module Development Program, NAS 9-15.

[redacted]

32. NASA-Manned Spacecraft Center, Memorandum to M. B. Trageser from M. E. Dell, EG131-5-65-374, 8 June 1965.

33. Massachusetts Institute of Technology, Instrumentation Laboratory, Quarterly Reliability and Quality Assurance Progress, Report R-457, 29 September 1964.

34. NASA-Manned Spacecraft Center, Minutes of the Sixth Command Service Module Block II Guidance and Control System Implementation Meeting, 18 August 1964.

35. North American Aviation, Inc., Environmental Control Systems Diagram, SID 64-1345, May 1965.

36. North American Aviation, Inc., Eighth Quarterly Reliability and Status Report, SID 62-557-8, 29 February 1964, Confidential.

37. North American Aviation, Inc., Tenth Quarterly Reliability and Status Report, SID 62-557-10.

38. North American Aviation, Inc., Thirteenth Quarterly Reliability and Status Report, SID 62-557-13, 30 April 1965, Confidential.

39. North American Aviation, Inc., Fifth Quarterly Reliability and Status Report, SID 62-557-5, 31 May 1965, Confidential.

40. North American Aviation, Inc., Study Guide Propulsion System, Course C3A412, 8 January 1965.

41. Grumman Aircraft Engineering Corporation, First Quarterly Reliability Status Report, LPR-550-1, March 1963, Confidential.

42. Grumman Aircraft Engineering Corporation, Eighth Quarterly Reliability Status Report, LPR-550-8, 1 May 1965, Confidential.

43. Grumman Aircraft Engineering Corporation, Environmental Control System Schematic Diagram, LDW 330-21000, August 1965.

44. Grumman Aircraft Engineering Corporation, Fifth Quarterly Reliability Status Report, LPR-550-5, 1 May 1964, Confidential.

45. Grumman Aircraft Engineering Corporation, Seventh Quarterly Status Report, LPR-550-7, 1 November 1964, Confidential.

46. NASA-Manned Spacecraft Center, "Letter O.G. Morris to Harvey Hall", 31 March 1965.

47. North American Aviation, Inc., Eleventh Quarterly Reliability Status Report, SID 62-557-11, 30 September 1964, Confidential.

48. North American Aviation, Inc., Fourth Quarterly Reliability Status Report, SID 62-557-4, February 1963, Confidential.

[redacted]

49. Grumman Aircraft Engineering Corporation, Minutes of LEM and CSM Spacecraft Reliability Analyses Data Review Meetings, 21 June 1965.

50. North American Aviation, Inc., Minutes of LEM and CSM Spacecraft Reliability Analyses Data Review Meetings, 30 June 1965 and 1 July 1965.

51. North American Aviation, Inc., Sixth Quarterly Reliability Status Report, SID 62-557-6, July 1963, Confidential.

52. North American Aviation, Inc., CSM Technical Specification, Block II, SID 64-1344, 22 February 1965.

53. Grumman Aircraft Engineering Corp., Communications Subsystem, Design Control Specification for, LSP-380-2, Amendment 5, 23 July 1964.

54. Grumman Aircraft Engineering Corp., Mission Related Design Requirements for the LEM Communications Subsystem, LED-540-23, Apollo Mission Planning Task Force, 15 November 1964, Confidential.

55. North American Aviation, Inc., CSM Master End Item Specification, Block II, SID 64-1345, 22 February 1965.

56. Grumman Aircraft Engineering Corp., Reliability Plan, 31 May 1963, Confidential.

57. Grumman Aircraft Engineering Corp., LEM Communications Subsystem Mathematical Model and Reliability Estimates, LED-550-57, 10 June 1965.

58. NASA-Office of Manned Space Flight, Letter from Dr. G. E. Mueller to Lt. Gen. L.I. Davis, Cmd'r. National Range Division, M-CMO 2200, 1 March 1965.

59. NASA-Manned Apollo Operations, Memorandum from J. K. Holcomb to Distribution, Subject: Minutes of Meeting to Review Apollo Mission Planning vs MSFN Readiness, 2 February 1965.

60. NASA/DOD, Study to Examine the Possibility of Single Point Failure in the Ground Operational Support of Gemini and Apollo, 22 March 1965.

61. NASA-Office of Manned Space Flight, Apollo Reliability and Quality Assurance Plan, NPC 500-5 (to be issued).

62. AVCO Corporation, Reliability Engineering Data Series - Failure Rates, April 1962.

[redacted]

ABBREVIATIONS

COMM - Communication

CSM - Command Service Module

DC - Direct Current

DOD - Department of Defense

DRM - Design Reference Mission

ECS - Environmental Control System

EDS - Emergency Detection System

ELS - Earth Landing System

EPS - Electrical Power System

EVA - Extra Vehicular Activity
Extra Vehicular Astronaut

FPS - Feet per second

GN&C (GNC) - Guidance, Navigation, Control

GOSS - Ground Operational Support System

HOSC - Huntsville Operational Support Center

I.U. - Instrument Unit

LEM - Lunar Excursion Module

LES - Launch Escape System

LCC - Launch Control Center

LiOH - Lithium Hydroxide

LOI - Lunar Orbit Insertion

LOX - Liquid Oxygen

MAO - Manned Apollo Operations

MAX. Q - Maximum Dynamic Pressure

MCC - Mid-course Correction

MSC - Manned Spacecraft Center

MSCC - Manned Spaceflight Control Center

MSFN - Manned Space Flight Network

NASA - National Aeronautics & Space Administration

PRO - Propulsion

RCS - Reaction Control System

REF - Reference

RP-1 - A Grade of Kerosene

SM - Service Module

SPS - Service Module Propulsion System

TD - Technical Direction

MIT - Massachusetts Institute of Technology

[redacted]

RA018-001-1

OFFICE OF MANNED SPACE FLIGHT

APOLLO PROGRAM

CLASSIFICATION CHANGE

TO - UNCLASSIFIED ~~CONFIDENTIAL~~

By authority of ~~T.D. No.~~ GDS Gp 4

Changed by AM Hubbard Date 11/75

[redacted] 1

APOLLO RELIABILITY AND QUALITY ASSURANCE PROGRAM QUARTERLY STATUS REPORT (U)

Request DRF

WITH APPENDIX C.

THIRD QUARTER 1965

8 OCTOBER 1965

NASA

ID NO. 3237-C

PREPARED BY

APOLLO RELIABILITY & QUALITY ASSURANCE OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, D.C. 20546

[redacted]

C68-548

[redacted]

RA018-001-1

Copy 17
of 225 Copies

APOLLO RELIABILITY
AND
QUALITY ASSURANCE PROGRAM
QUARTERLY STATUS REPORT (U)

THIRD QUARTER 1965

8 October 1965

[redacted] 4
Dow[redacted]ear Intervals;
Declassifie[redacted]Years,
DOD D[redacted]00.10

This d[redacted]contains information affecting[redacted]ates wit[redacted]the meaning of the[redacted]794. The tr[redacted]nsmission[redacted]of its contents in any manner to an unauthoriz[redacted]person is p[redacted]by law.

Prepared by

Apollo Reliability and Quality Assurance Office
National Aeronautics and Space Administration
Washington, D.C. 20546

[redacted]

The following parts of this document are CONFIDENTIAL:

Summary - pages xi through xxii

Section 1 - pages 1-1 through 1-76

Section 2 - pages 2-1 through 2-72

FOREWORD

Apollo Program Reliability and Quality Assurance Status Reports are prepared quarterly by the Reliability and Quality Assurance Program Office for the Apollo Program Director based upon an analysis of information supplied by Reliability and Quality Assurance groups at the Manned Space Flight Centers in Houston, Huntsville, and Cape Kennedy. These reports document accomplishments during the period, current status of the Reliability and Quality Assurance Program, and action planned for continuing reliability improvement in the management and hardware areas of the Apollo Program.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

[redacted]

SUMMARY

GENERAL

This status report documents the progress of the Apollo Reliability and Quality Assurance Program during the third quarter of 1965, and it covers the following three areas: Apollo Saturn IB flight missions, Apollo-Saturn V flight missions, and Reliability and Quality Assurance Program Management.

Sections 1 and 2 contain current reliability and quality assurance status of the launch vehicles, spacecraft, and ground support equipment associated with the Apollo-Saturn IB and Apollo-Saturn V missions. Reliability analyses of the Apollo-Saturn 201 and 504 missions are included. Details of the reliability analysis of the Apollo-Saturn 504 MLL mission are contained in Appendix C - <u>Apollo-Saturn 504 Mission Reliability Analysis</u>, a separate document being issued concurrently with this report. Status of the R&QA Program Management activities during the report period are covered in Section 3.

APOLLO-SATURN IB FLIGHT MISSIONS

SIGNIFICANT ACCOMPLISHMENTS

The following accomplishments during the report period are of significance in assessing progress in the early Apollo-Saturn IB flight missions of the Apollo Program:

a. A reliability analysis of the Apollo-Saturn 201 mission based on latest predictions and mission profiles was conducted.

b. Ninety-two percent of the requirements of NPC 250-1 are contractually required of the Saturn IB launch vehicle contractors. Of this 92 percent requirement, 83 percent are being implemented.

c. Supporting ground tests were accelerated to decrease mission risk of the Apollo-Saturn 201 flight.

d. Acceptance testing of the S-IB-1 and S-IVB-201 stages was completed and the stages were delivered to Kennedy Space Center.

e. Critical items lists for the launch vehicle stages of 201 mission were updated to reflect the hardware as delivered.

[redacted]

SUCCESS PREDICTION

For the first launch (201) in the Apollo-Saturn IB series, the major elements of risk are concerned with the operation of the S-IB and S-IVB stages. Relative contributions to unreliability based on predicted values are depicted in Figure A.

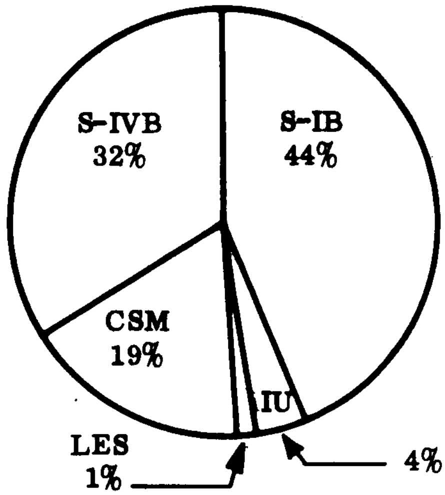


Figure A. Apollo-Saturn 201 Mission Percent Contribution to Unreliability Based on Predictions.

Predicted values indicate a mission success probability of 0.899 which exceeds the allocated goal of 0.841. An event-by-event comparison of probable reliability and allocated goals based on predicted values is shown in Figure B.

In the event of a major malfunction in the 201 mission launch vehicle, action may be initiated by ground command to permit recovery of the Command Module. The probability of contingency (abort) success based on predicted values was computed as 0.992 using the Launch Escape Subsystem and 0.989 using the Service Propulsion Subsystem for separation power.

[redacted]

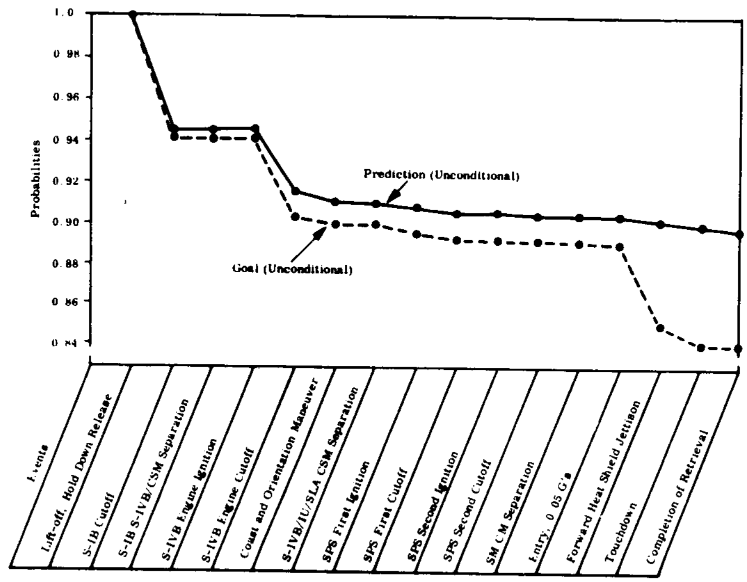


Figure B. Apollo-Saturn 201 Computed Mission Success Probabilities

IMPROVEMENT ACTION

Action for program improvement will be concentrated as indicated in the following paragraphs.

Component Qualification Tests

Qualification tests of flight critical hardware are behind schedule (Figure C). An evaluation of the resultant risk to the 201 mission will be coordinated by the Reliability and Quality Assurance Program Office prior to the Program Director's Flight Readiness Review.

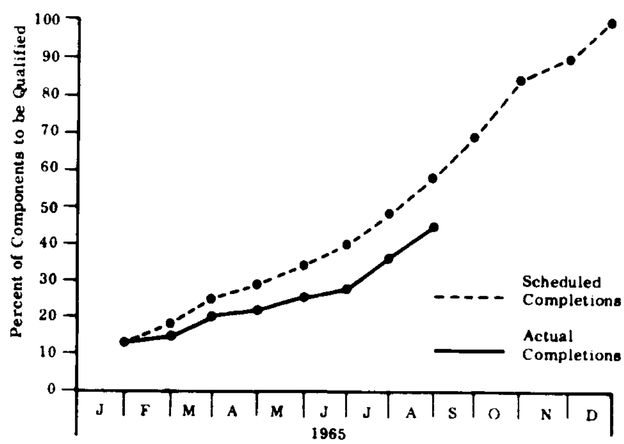


Figure C. Apollo-Saturn 201 Component Qualification Status

[redacted]

Hardware Delivery

Late deliveries of the S-IU stage and spacecraft to KSC may compromise checkout of the 201 mission flight vehicle. The Reliability and Quality Assurance Program Office will monitor reliability and quality assurance activities at KSC to insure that checkout plan changes will not degrade mission reliability.

S-IB-1 Stage Prediction

The Number 1 fuel tank on the S-IB-1 stage was damaged by overpressurization during wet tests at KSC and is being replaced by a new thin-wall design tank from the S-IB-6 stage. The Reliability and Quality Assurance Program Office will review results of current tests to determine their effect on the reliability prediction for the S-IB-1 stage.

Ground Support Equipment

Ground support equipment is being accepted at the contractor's plant by KSC, but no plans or procedures exist for checkout upon receipt at the site. The Reliability and Quality Assurance Program Office is supporting KSC in the development and implementation of reliable receiving inspection procedures.

APOLLO-SATURN V FLIGHT MISSIONS

SIGNIFICANT ACCOMPLISHMENTS

During the reporting period, the following significant accomplishments were made in the Apollo-Saturn V flight mission:

a. The initial issue by MSFC of the "Saturn 501 Reliability Math Model" dated 7 September 1965 was published. The results of criticality analyses for each of the stages were included in the document. It is anticipated that the document will be revised and updated in the near future. This represents the first identifiable major reliability action solely for the 501 mission.

b. The R&QA Program Office completed an "Apollo-Saturn 504 Mission Reliability Analysis" based on predictions and mission profiles, which is included as Appendix C to this report.

c. Mission success criteria for the manned lunar landing mission have been revised to reflect the 34.7-hour lunar stay time. Apportionments are currently being re-evaluated by the contractors in an effort to reflect latest mission profile and ground rules. Contractor mission success predictions for LEM are somewhat lower due primarily to the extended lunar stay time. CSM mission success predictions are expected to follow the same pattern.

d. 86 percent of the requirements of NPC 250-1 are contractually required of the Saturn V contractors. Of this 86 percent requirement, 74 percent are being implemented.

SUCCESS PREDICTION

Crew safety and mission success probabilities for the Apollo-Saturn 504 Manned Lunar Landing mission are covered in detail in Appendix C. The estimates were prepared using documented reliability information obtained from Centers and contractors.

Figure D shows the percentage contribution by stages and modules to present predicted mission unreliability.

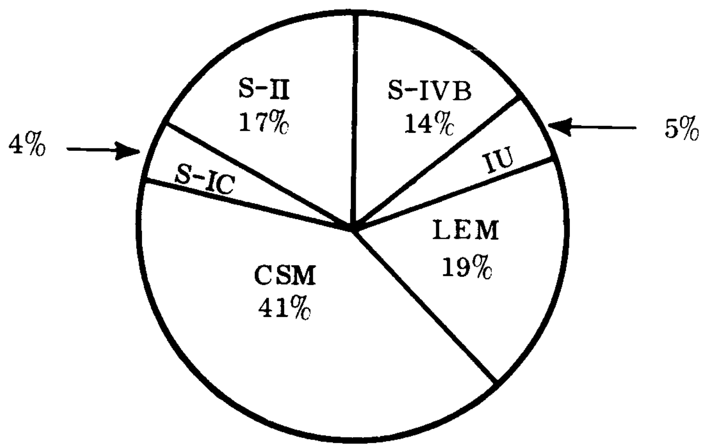


Figure D. Apollo-Saturn 504 Mission Percent Contribution to Mission Unreliability Based on Predictions

The percentage contribution to unreliability of the fifteen major phases of the in-flight portion of the mission are illustrated in Figure E.

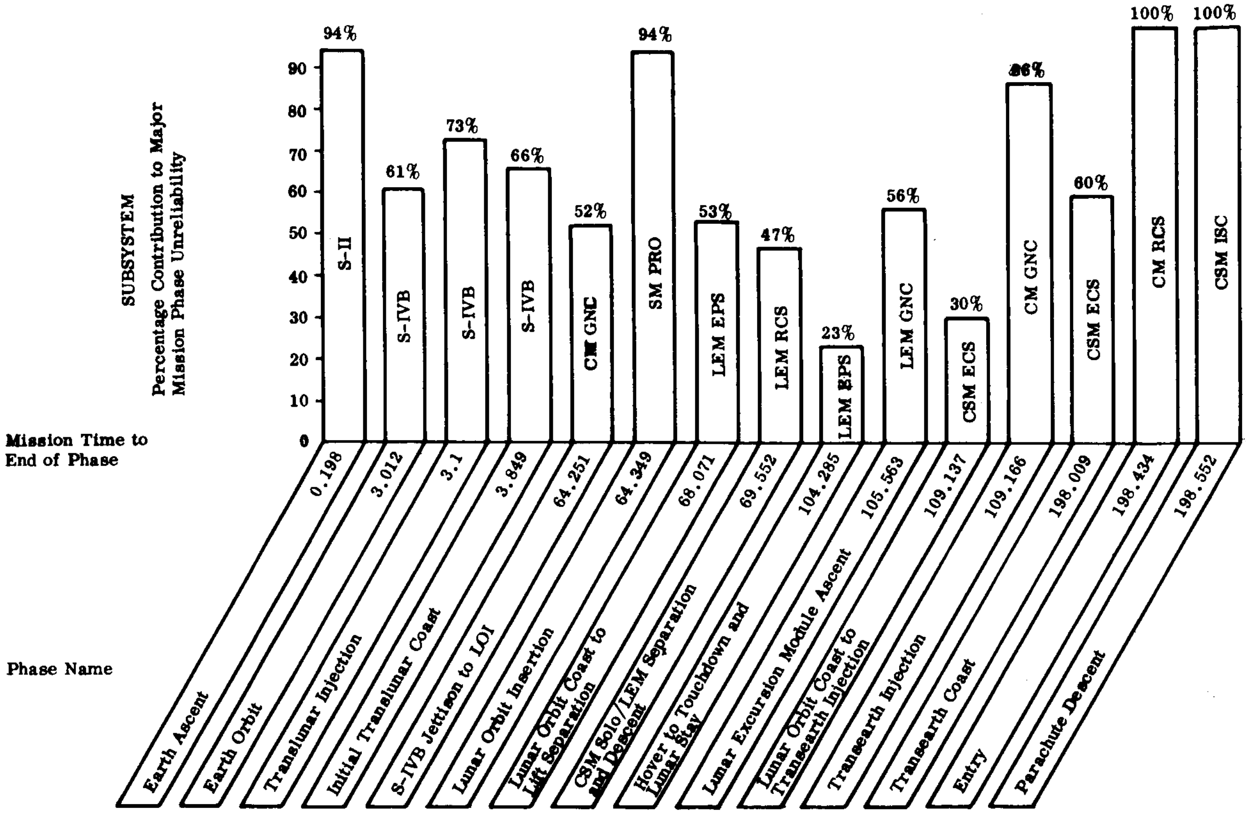


Figure E. Apollo Saturn 504 Manned Lunar Landing Mission Major Percentage Contribution and Contributor to Mission Unreliability Versus Mission Phase

The transearth coast phase ranks highest in probability of crew loss since this is the longest phase and neither primary nor secondary abort capability exists. The S-IVB jettison to lunar orbit is estimated to have the highest probability of mission loss primarily because operational ground rules dictate that the mission be aborted if any of the guidance and navigation equipments fail prior to the Lunar Excursion Module descent.

Based upon Center/contractor reliability apportionment, the estimates of mission success and crew safety probabilities are 0.96 and 0.73, respectively.

The Apollo Program Office predicted crew safety and mission success probabilities for the manned lunar landing mission are 0.96 and 0.52, respectively, as shown in Figure F. These estimates are based on Center/contractor reliability data.

[redacted]

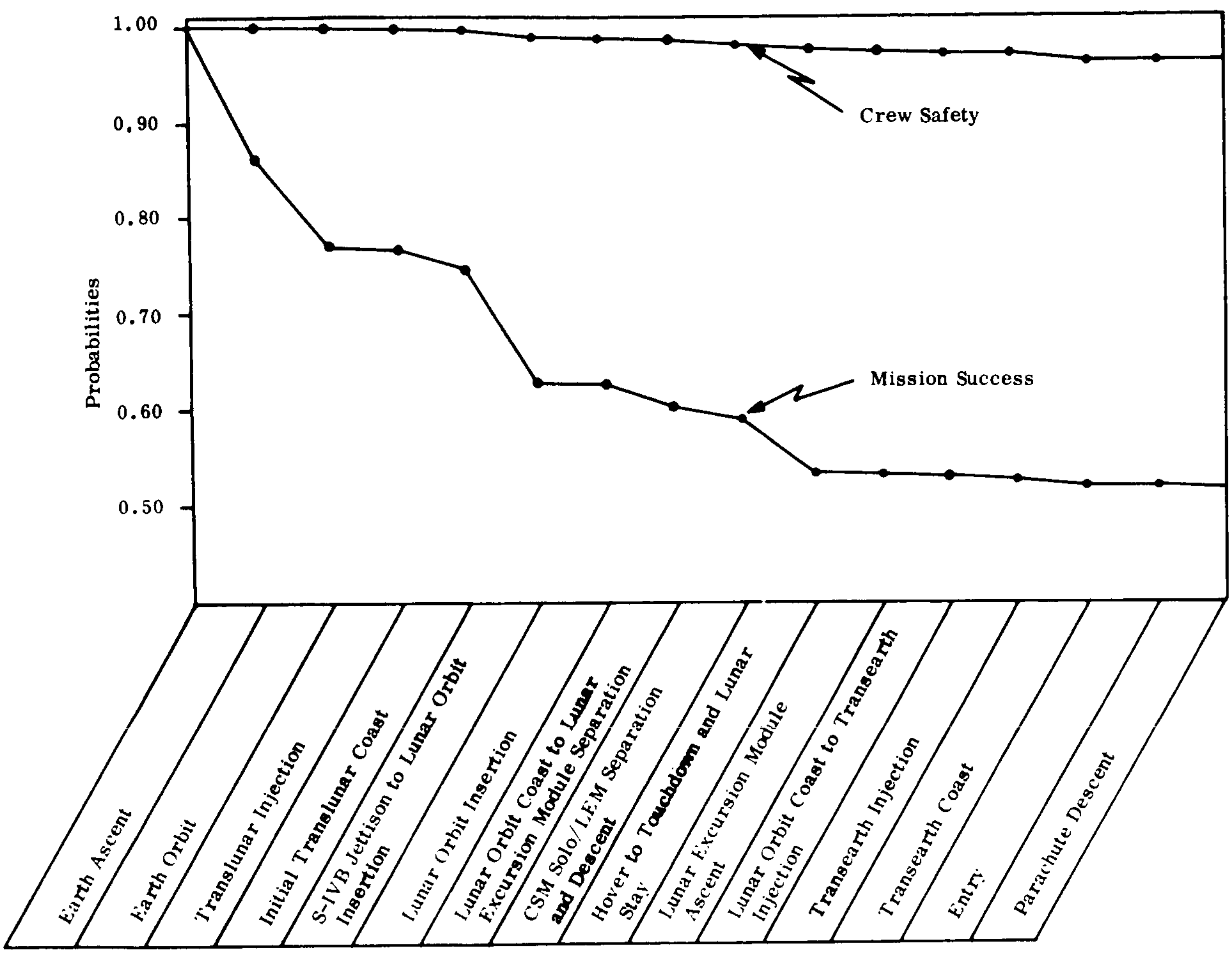


Figure F. Apollo-Saturn 504 Computed Mission Success and Crew Safety Probabilities

IMPROVEMENT ACTION

The Reliability and Quality Assurance Program Office activity during the next quarter will be directed toward reliability improvement as indicated in the following paragraphs.

S-IVB Jettison to Lunar Orbit Insertion Phase

Current mission reliability analysis indicates the S-IVB jettison to lunar orbit insertion phase is the prime contributor to mission unreliability and also ranks high (second) as

[redacted]

a relative safety hazard. This condition is due to the abort criteria and abort duration. The Apollo Reliability and Quality Assurance Program Office will examine this problem and will consider possible methods of mitigating the severity of the condition.

Launch Availability Analysis

Criteria necessary to meet the launch window have not been defined fully nor has a comprehensive analysis of launch availability been undertaken. Fragmented partial analyses are currently underway at various levels, but a common over-all approach is lacking. The Reliability and Quality Assurance Program Office will publish the first progress report during the next quarter.

Ground Operational Support System (GOSS) Reliability

There is presently no comprehensive body of reliability data on Apollo-Saturn GOSS. The Reliability and Quality Assurance Program Office will analyze the GOSS/ space vehicle functional interrelationships and report on progress during the next quarter.

RELIABILITY AND QUALITY ASSURANCE PROGRAM MANAGEMENT

SIGNIFICANT ACCOMPLISHMENTS

During the report period, Apollo Reliability and Quality Assurance Offices initiated or implemented additional plans for the continuing improvement of program reliability through the coordinated use of more effective measurement, report, and control techniques. Included were the following:

a. The Apollo Reliability and Quality Assurance Program Office completed and issued October 1965 to Manned Space Flight Centers the over-all "Apollo Reliability and Quality Assurance Program Plan" (NHB-5300.1).

b. The initial "Reliability and Quality Assurance Quarterly Status Report" on the Spacecraft was issued 15 September 1965 by MSC/ASPO.

c. MSC has initiated monthly R&QA Program Review meetings with their prime contractors. Review meetings were held with NAA, ACED, and GAEC during the reporting period.

[redacted]

d. MSF Centers conducted 12 R&QA audits of prime system contractors and selected subcontractors.

e. Two lunar landing mission simulations were completed and a third simulation was started during the report period. Guidance and navigation performance of switching functions exceeded 0.99. Flight control and guidance and navigation performance were within approved tolerance limits.

f. The "Metrology Requirements Manual" was completed during the quarter by the Apollo R&QA Program Office.

g. The Manned Flight Awareness Program initiated by MSFC for R&QA motivational purposes has been extended through additional showings of the film, "The Essential Component", particularly for indoctrination of new personnel. MSFC's traveling Manned Flight Awareness exhibit was presented at 12 Saturn contractor and subcontractor locations during the report period.

h. MSC/ASPO revised and updated, August 1965, the "Apollo Spacecraft Program Office Reliability Requirements Manual".

i. MSC/ASPO completed preparation of the R&QA Policy for Material Review Board activities on Apollo Spacecraft Program.

j. An Apollo Parts and Materials Management Panel was established to encourage cooperation and information exchange.

k. KSC Reliability and Quality Assurance Office issued "Failure Reporting Summary, SA-8 Pre-Launch Test and Checkout at KSC" 7 July 1965 and issued "Failure Reporting Summary, SA-10 Pre-Launch Test and Checkout at KSC" 10 September 1965.

l. The draft report of the "Electromagnetic Compatibility Principles and Practices" manual, dated May 1965, was approved and issued by the Apollo R&QA Office. This manual will be used by NASA as source and reference material for electromagnetic compatibility (EMC) awareness courses to be presented to management and engineering.

IMPROVEMENT ACTION

During the next period, action will be taken for program improvement as indicated in following paragraphs.

[redacted]

Center Status Reporting

Formal level II reports have not yet been issued from Reliability and Quality Assurance Offices at KSC or MSFC. Apollo Reliability and Quality Assurance Office is continuing to assist MSF Centers by developing report requirements and procedures.

Program Audits

Appraisal of quality audit program at MSC indicates effectiveness below requirements. The Apollo Reliability and Quality Assurance Office will review MSC's improvement action.

System Nonperformance Analysis

July and September Program Reviews revealed a lack of failure information and many unresolved failures. An Apollo Program Directive for Failure Reporting based on the September review and a previous interim instruction will be prepared and Reliability and Quality Assurance Office personnel will assist MSF Centers in its implementation.

Single Point Failure Analysis

When issued, the Single Point Failure Analysis Directive will be coordinated with other Apollo Program Office Directorates and MSF Centers to insure that requirements of the directive are understood and subsequent implementation will furnish required information.

Reliability Management Study

Results of a Reliability and Quality Assurance Office study indicate the need for improvement in reliability interfaces, relationships, and implementation procedures at the program level. Detailed reliability milestones will be established in association with Manned Space Flight Schedules.

Reliability Modeling

Successful development of a compatible family of reliability analysis models is contingent on the adoption and use of a common mission profile by contractors and MSF Centers at all levels.

At MSC, major organizational and technical requirements have been established, prime contractor models have been reviewed, and a level II model is being assembled. Formal guidelines issued by the Reliability and Quality Assurance Program Office for conducting reliability estimations are currently being reviewed by MSF Centers. Reliability and Quality Assurance Office personnel are continuing to coordinate with MSF Centers to achieve a common mission profile.

At MSFC, meetings have been held during September to discuss the level II launch vehicle model. As a result of these meetings, level II and level III model reviews will be scheduled.

KSC has concentrated on the development of Failure Modes and Effects analysis and on "Alternate Modes of Operation" for those items of Ground Support Equipment for which KSC has prime responsibility. Both of these activities entail the construction of models which are compatible with those being developed by MSC and MSFC.

This Page Is Intentionally Blank

SECTION 1: APOLLO-SATURN IB MISSIONS

1.1 GENERAL

1.1.1 INTRODUCTION

This section discusses the reliability and quality status of the Apollo-Saturn IB flight mission equipments with specific emphasis on the Apollo-Saturn 201 Mission. The scope of this report has been broadened to include qualitative data on the Apollo-Saturn 202 and 203 missions. For purposes of clarity, each of the subject missions is discussed separately.

Major accomplishments during the reporting period encompass both hardware and software activities which include the following:

a. Completion of the functional reliability drawings for the S-IB-3 stage and the critical items list for the S-IB-4 stage.
b. Completion of failure rates and logic data for use in the S-IB-2 reliability evaluation model.
c. Performance of reliability assurance evaluations on Saturn IB Launch Vehicle contractors by the MSFC Reliability and Quality Assurance Office.
d. Completion of approximately 80 percent of the ground tests in support of the Apollo-Saturn 201 Mission.

Problems that could degrade reliability in the early 200 series flights are listed as follows:

a. Slippage in the delivery of the S-IU-201 stage to KSC caused by the ESE checkout station activation at MSFC could degrade the test program at KSC, adding risk to the Apollo-Saturn 201 Mission.
b. The Reaction Control System titanium oxidizer tank and bladder problems discussed in paragraph 1.5 could have a serious effect on the Apollo-Saturn mission. NASA has stated that the Apollo-Saturn 201 and 202

missions can be flown only with severe curtailment in the functional operation of the tank assemblies.

c. Replacement of the No. 1 fuel tank on the S-IB-1 stage precipitated by overpressurization damage during wet tests at KSC could degrade the reliability of the Apollo-Saturn 201 flight. The replacement tank was taken from the S-IB-6 stage and is of the new thin-wall configuration presently under test.

Implementation of the reliability requirements of NPC 250-1 by the Saturn IB Launch Vehicle contractors is shown on Figure 1-1. The degree of contractor compliance with the contractual requirements is subject to review since documentation in support of quantitative compliance was lacking in most areas. MSFC project management has received the results of these reliability assurance evaluations along with specific recommendations for upgrading the contractor's reliability programs.

1.1.2 APOLLO-SATURN 201 MISSION

1.1.2.1 <u>Mission Reliability Analysis</u>

1.1.2.1.1 Summary

Since complete Center/contractor reliability analyses of the Apollo-Saturn 201 Mission are not available, predictions made independently by the Apollo Program Office (APO) have been compiled and compared to the similar available contractor predictions for Apollo-Saturn 201 Mission success. No common basis existed for the contractor predictions; some were made on the conventional reliability basis, some on the "no stage loss" basis, and others are the results of preliminary computations on a "no uncorrected failures" basis. The APO predictions were made on the conventional reliability basis.

The planned mission profile has been divided into phases, each phase beginning and ending with a definite event which can be monitored during the flight. Mission success models have been developed to represent the equipment use and status in each modeled phase. The conditional probability is the probability of each phase being completed provided it has been started, and the unconditional probability is the probability of the

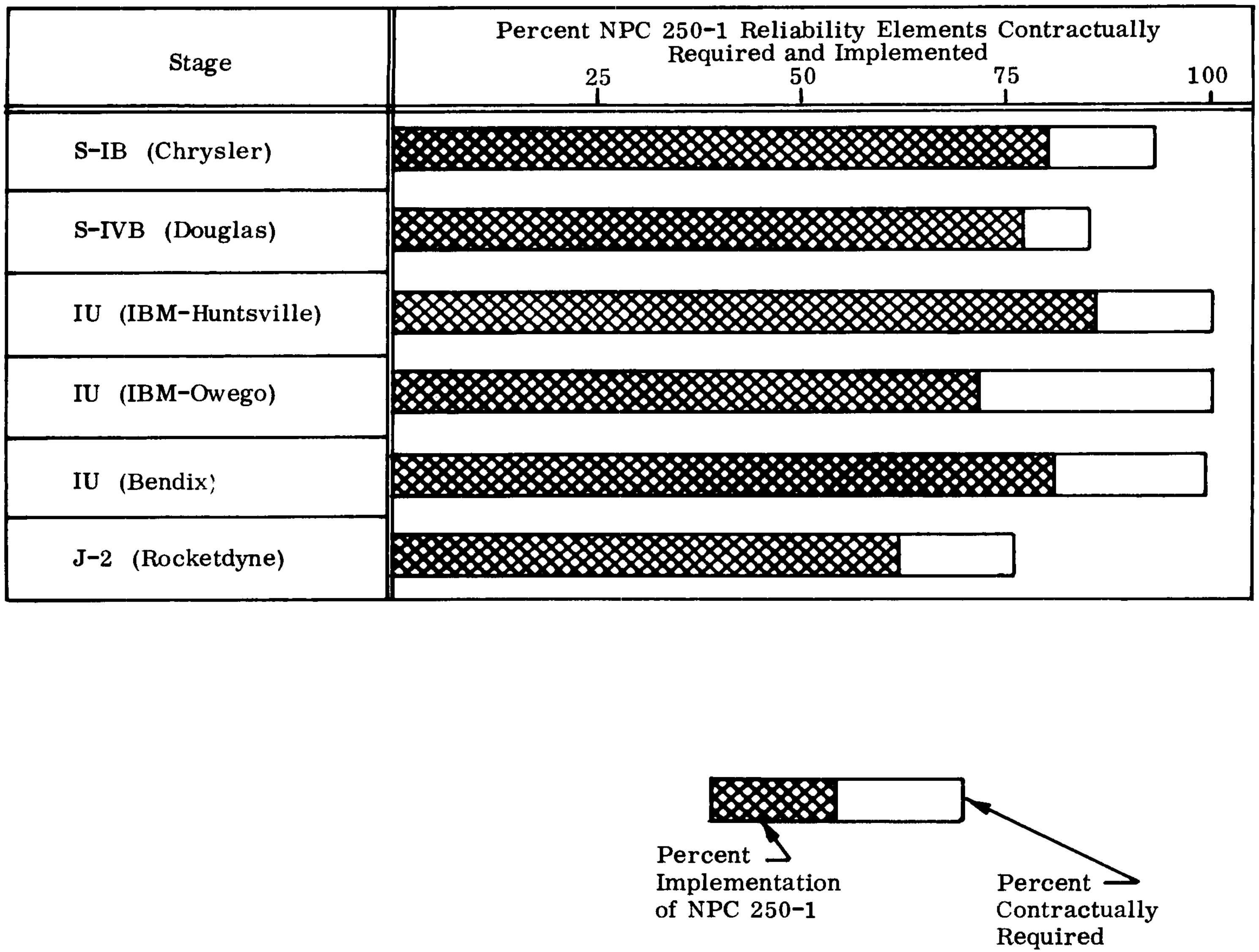


Figure 1-1. Saturn IB Program Summary Reliability Assurance Evaluation Based on NPC 250-1

mission proceeding to the start of each phase. These probabilities were computed using the models and predicted values.

Two types of contingency situations were modeled, and their probabilities of success were computed using predicted values. Such contingency plans can be used for the Apollo-Saturn 201 Mission only by command from the ground.

Mission success is defined in the "Apollo Reliability Estimation Guidelines" as "the attainment of all major objectives of the mission as defined in the mission and flight directive ...."

Data for assessing or predicting the reliability of the Launch Complex and Eastern Test Range (or Ground Operational Support System) were not available; thus, the effects of these systems were omitted from the computations by assuming a value of 1.0 for their reliabilities.

1.1.2.1.2 Mission Profiles

No changes were found for the Apollo-Saturn 201 Mission Profile listed in the Quarterly Status Report for the Second Quarter 1965. To assist in comparison of missions, the 201 Profile is repeated herein as Figure 1-2.

1.1.2.1.3 Mission Success Goals

No changes have been received in the goals, listed in Figure 3-23 of the Quarterly Status Report for the Second Quarter 1965, relating to the Apollo-Saturn 201 Mission. General S-IB, Instrument Unit, and Block I Spacecraft goals were used as approximations because goals specifically for the 201 Mission were not available. The computed probabilities based on goals may be considered pessimistic, since the 201 Mission involves shorter time periods than the earth orbital or reference mission (40 minutes compared to over 200 hours).

1.1.2.1.4 Mission Success Predictions

The results of computations for mission success of the Apollo-Saturn 201 Mission, using the profile of Figure 1-2 and the system/subsystem predictions listed in

[redacted]

Elapsed Time in Seconds		Events	Normalized Profile		
MSFC Profile (19)	MSC Profile (35)	(A subphase extends from an event to the next event)	Elapsed Time in Seconds	Subphase Number	Subphase Time in Seconds
		Start Countdown			
				1	---
0.0	0.0	Liftoff, Hold Down Release	0.0		
				2	146.3
146.3	144.3	S-IB Cutoff	146.3		
				3	0.8
147.1	145.1	S-IB S-IVB/CSM Separation	147.1		
				4	4.8
151.9	149.9	S-IVB Engine Ignition (90% Thrust)	151.9		
				5	454.9
606.8	615.8	S-IVB Engine Cutoff	606.8		
				6	249.0
	855.8	Coast and Orientation Maneuver	855.8		
				7	20.0
	875.8	S-IVB/IU/SLA CSM Separation	875.8		
				8	390.2
	1266.0	SPS First Ignition	1266.0		
				9	180.0
	1446.0	SPS First Cutoff	1446.0		
				10	15.0
	1461.0	SPS Second Ignition	1461.0		
				11	10.0
	1471.0	SPS Second Cutoff	1471.0		
				12	31.5
	1502.5	SM CM Separation	1502.5		
				13	112.5
	1615.0	Entry, 0.05 G's	1615.0		
				14	425.0
	2040.0	Forward Heat Shield Jettison	2040.0		
				15	441.0
	2481.0	Touchdown	2481.0		
				16	(48 Hours Max.)
	----	Retrieval	(48.68 Hours Max.)		

Figure 1-2. Apollo-Saturn 201 Mission Profile

[redacted]

paragraphs 1.2 through 1.5, are shown in quick reference form in Figure 1-3 and in detailed form in Figure 1-4. The assumption is made that all flight critical systems are operable or have a reliability of 1.0 at liftoff.

The spacecraft contractor had performed a preliminary assessment of the Spacecraft 009 equipment and planned to follow this assessment with final predictions during September 1965. Since this final information was not available for the preparation of this report, the Apollo Program Office performed a reliability prediction for the spacecraft. This prediction involved conventional reliability techniques based on available contractor models and reliability data; where contractor information was not available, state-of-the-art failure rates and synthesized logic diagrams were used. Environmental modifying or "K-factors" were used to account for induced environments occurring during the mission.

In the preparation of the mission computations for this report, predictions supplied by contractors were used for the launch vehicle.

Spacecraft subsystem reliabilities that were significantly different from the preliminary contractor assessments are listed in the following:

	APO Calculated	Contractor Assessments
Electrical Power Subsystem	0.999534	0.999966
Stabilization Control Subsystem	0.995630	0.999634
Communications	0.996670	0.999761
Earth Landing System	0.997972	0.999903
Environmental Control Subsystem	0.998910	None
Separation System	0.998337	None

Mission objectives paraphrased from the "Apollo-Saturn 201 Mission Directives" that were issued by OMSF, MSFC, and MSC are listed in Figure 1-5, with the probability indicated for successfully accomplishing each objective. Because the phases used for modeling begin and end with specific events that can be monitored during the flight, the accomplishment of a mission objective may either coincide with the end of a phase or occur during a phase.. An accomplished objective may involve the operation of hardware

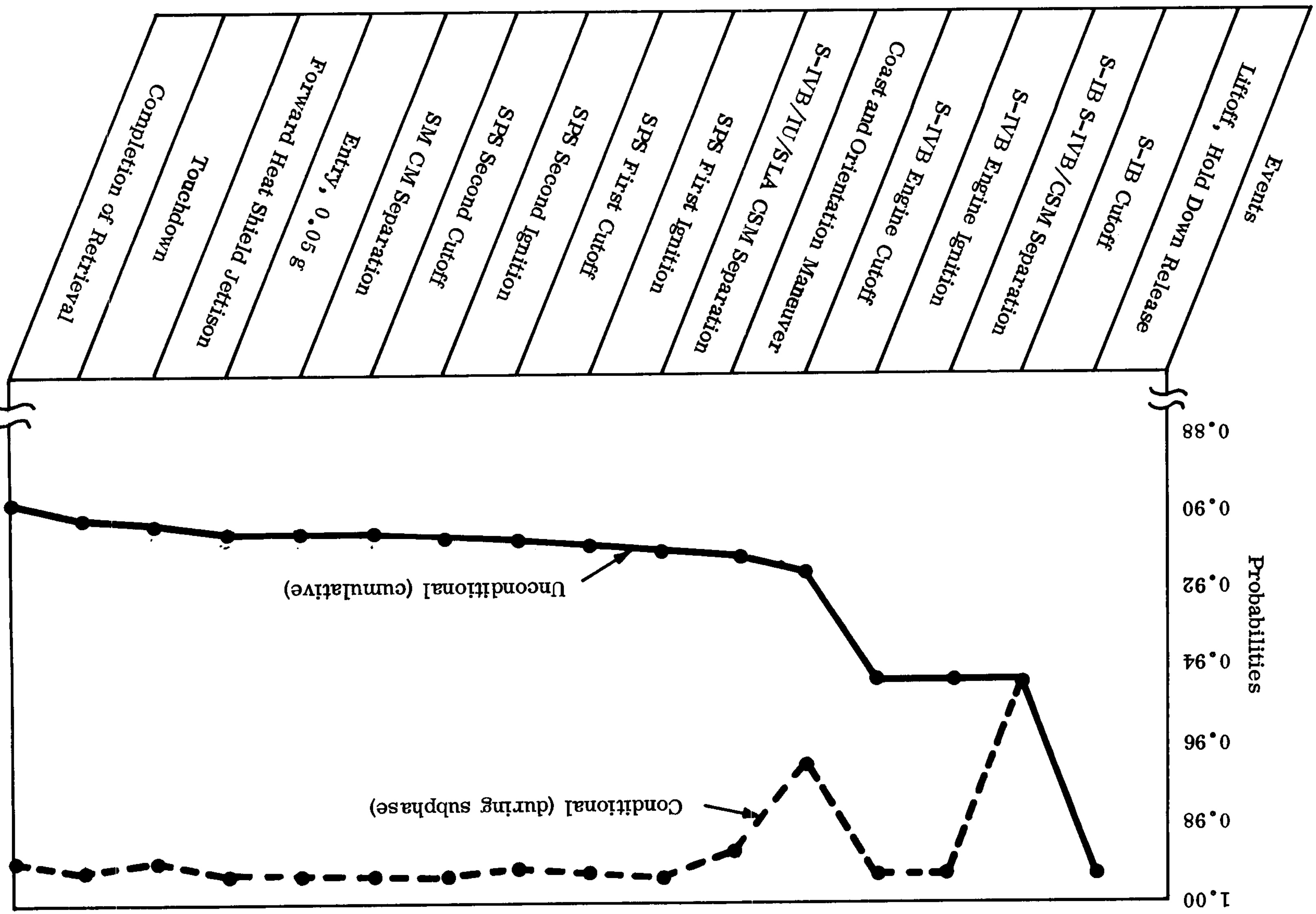


Figure 1-3. Apollo-Saturn 201 Computed Mission Success Probabilities

Events (A Subphase extends from an event to the next event)	Subphase Number	Computed Mission Success: Goals — To Beginning of Period (unconditional)	Goals — During Subphase (conditional)	Predictions — To Beginning of Period (unconditional)	Predictions — During Subphase (conditional)
Start Countdown					
	1	(not modeled, assumed to be 1.0)			
Lift-Off, Hold Down Release					
	2	1.0	0.941793	1.0	0.947569
S-IB Cutoff					
	3	0.941793	0.999979	0.947969	0.999748
S-IB S-IVB/CSM Separation					
	4	0.941774	0.999890	0.947730	0.999923
S-IVB Engine Ign. (90% thrust)					
	5	0.941671	0.960420	0.947657	0.969033
S-IVB Engine Cutoff					
	6	0.904400	0.996069	0.918311	0.992676
Coast & Orientation Maneuver					
	7	0.900845	0.999682	0.911585	0.999388
S-IVB/IU/SLA CSM Separation					
	8	0.900559	0.997011	0.911027	0.997992
SPS First Ignition					
	9	0.897868	0.995804	0.909198	0.997209
SPS First Cutoff					
	10	0.894101	0.999888	0.906660	0.999974
SPS Second Ignition					
	11	0.894001	0.999767	0.906636	0.999480
SPS Second Cutoff					
	12	0.893793	0.999758	0.906165	0.999961
SM CM Separation					
	13	0.893577	0.999139	0.906130	0.999810
Entry, 0.05 g					
	14	0.892808	0.954170	0.905958	0.995733
Forward Heat Shield Jettison					
	15	0.851891	0.988539	0.902092	0.998668
Touchdown					
	16	0.842128	0.998792	0.900890	0.997952
Retrieval					
Over-all (At End of Retrieval)		0.841111	---	0.899045	---

Figure 1-4. Apollo-Saturn 201 Summary by Phases

[redacted]

Mission Objectives (Compendium) (8)
1. Determine structural loading of the spacecraft adapter (SLA) when subjected to the Saturn IB launch environment
2. Demonstration of S-IB/S-IVB separation
3. Demonstration of launch escape system separation
4. Demonstration of launch vehicle structural integrity
5. Verification of launch vehicle propulsion subsystem operation
6. Evaluate performance of the open-loop emergency detection subsystem
7. Verification of launch vehicle guidance and control subsystem operation
8. Demonstration of launch vehicle - command/service module (CSM) separation
9. Determine long duration service propulsion subsystem (SPS) performance including shutdown
10. Demonstrate restart of service propulsion subsystem (SPS) following long duration burn
11. Verification of spacecraft service module reaction control subsystem (SM-RCS) operation

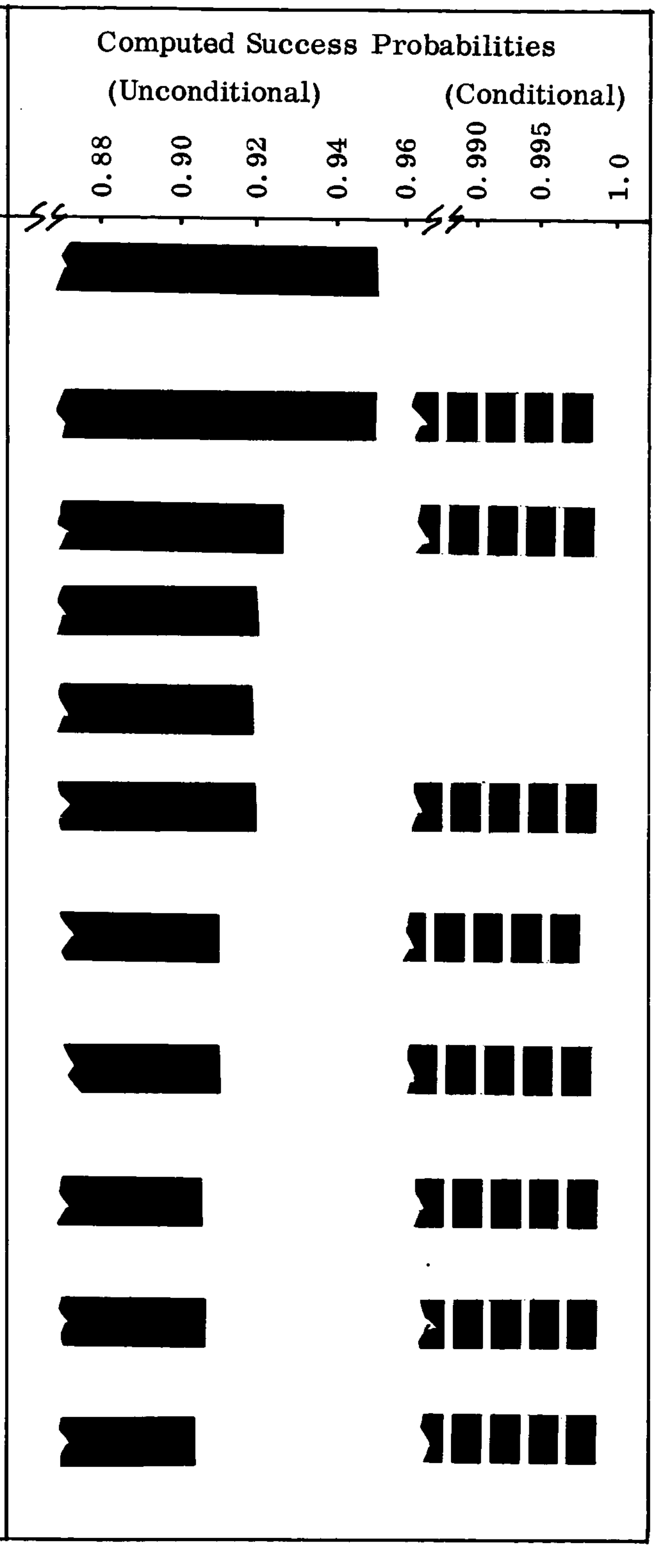
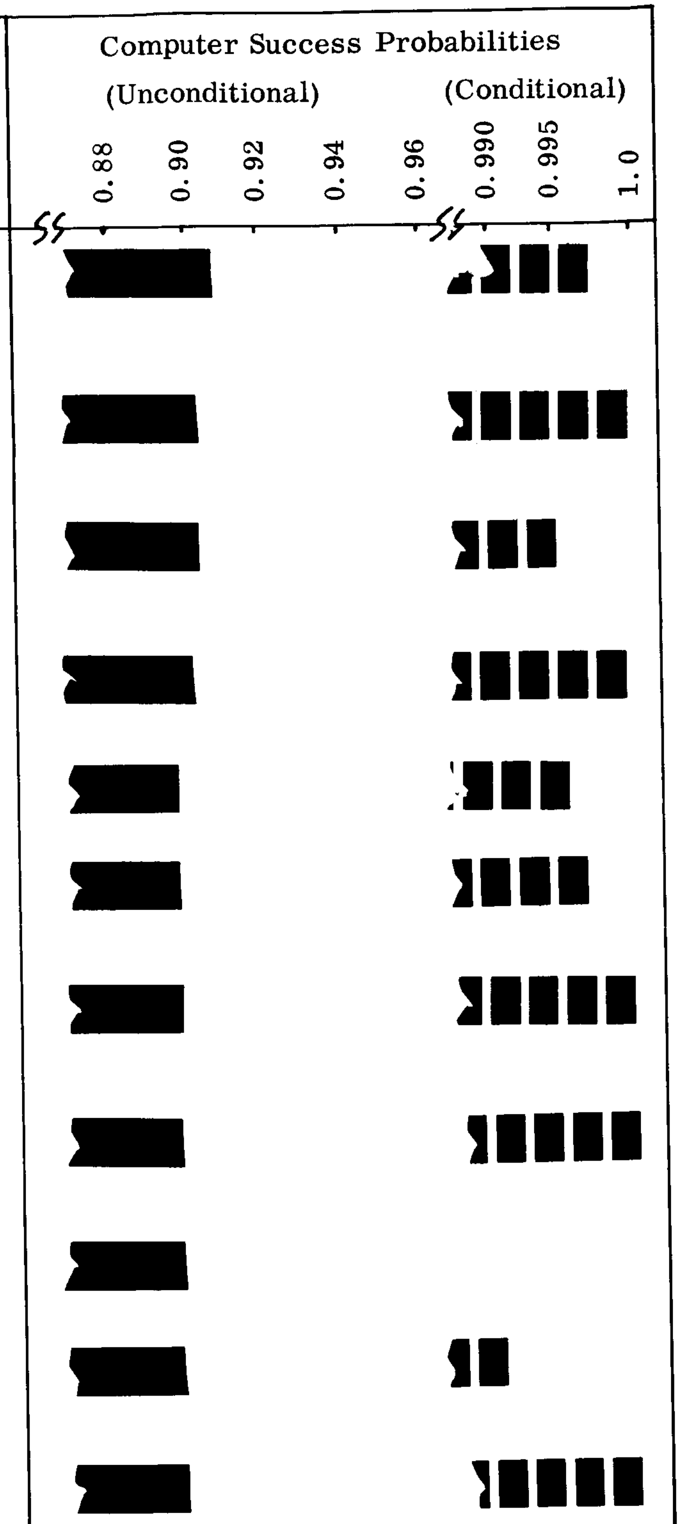


Figure 1-5. Apollo-Saturn 201 Mission Objective - Predictions (Sheet 1 of 2)

[redacted]

Mission Objectives (Compendium)
12. Demonstration of service module-command module separation
13. Evaluate command module heat shield ablator performance during high heat-rate entry
14. Verification of spacecraft stabilization control subsystem (SCS) operation
15. Verification of spacecraft command module reaction control subsystem (CM-RCS) operation
16. Verification of spacecraft communication subsystem operation
17. Verification of spacecraft earth landing subsystem (ELS) operation
18. Verification of spacecraft environmental control subsystem (ECS) operation
19. Verification of spacecraft electrical power subsystem (EPS) operation
20. Determine adequacy of recovery aids
21. Determine command module adequacy for manned entry from low earth orbit
22. Demonstration of spacecraft structural integrity



LEGEND: Indicates unconditional probability of activity being completed
Indicates conditional probability of activity being completed

Figure 1-5. Apollo-Saturn 201 Mission Objective - Predictions (Sheet 2 of 2) at only one specific time (for example, the separation of the CSM from the S-IVB/IU/SLA), but the start of this event requires the successful completion of all preceding phases. The unconditional or cumulative probability of the mission proceeding to the completion of each objective is listed in Figure 1-5. Conditional probabilities of completion for most objectives (provided the functions involved have been started) are also shown. Conditionals for some objectives could not be calculated, since the available system/subsystem breakdown does not permit separation of the systems needed.

1.1.2.1.5 Comparison of Goals and Predictions

For the Apollo-Saturn 201 Mission, the reliability predictions for all stages equal or exceed the estimated goals (goals were used for this mission because very few contractual apportionments exist). The over-all probability of mission success as derived from the mission specification and supporting documentation has the goal of 0.841. It is predicted to be 0.899. Detailed comparisons by phases are shown in Figure 1-4.

1.1.2.1.6 Contingencies

In the event of major malfunction during the interval between ignition of the S-IB engines and separation of the Command and Service Module from the Launch Vehicle, action may be initiated by ground command which will separate the Command Module (CM) from the remainder of the vehicle and allow it to return by means of its Earth Landing System.

Provisions have been made in the Apollo-Saturn 201 Mission Plans for two types of contingencies (often called "aborts"). Use of the Launch Escape System (LES) can be initiated at any time from S-IB ignition to the jettisoning of the LES after S-IVB ignition, approximately 170 seconds after liftoff. The Service Propulsion System (SPS) contingency can be used at any time from LES jettisoning to the S-IVB CSM separation, approximately 700 seconds after the LES jettisoning. If either contingency is required, one primary mission objective, "evaluation of the Command Module heat shield ablator performance during high heat-rate entry", cannot be achieved. Other mission objectives which are demonstrated during early phases of the flight may be reached, depending upon the flight time prior to initiation of the contingency.

The predicted values of contingency success are computed to be 0.992 for the LES contingency and 0.989 for the SPS contingency.

1.1.2.2 Qualification Test Summary

The summary of component qualification status is shown on Figure 1-6. This status reflects flight critical components for the Saturn IB Launch Vehicle and total component qualification for Spacecraft 009. All qualification test programs are behind schedule with the exception of the S-IB stage. Repeated failures in the mandatory test environments of the Development Qualification (DE/Q) tests on the S-IVB stage have delayed start of formal qualification. Based on present analysis, the formal qualification tests are not expected to be complete before the latter part of March 1966, instead of 15 October 1965, as scheduled. A review of late test completions against the requirements of the Apollo-Saturn 201 Flight are now underway.

1.1.2.3 Ground Support Tests

The status of the ground tests in support of the Apollo-Saturn 201 Mission as defined in the "OMSF Flight Mission Directive for Apollo-Saturn 201" is shown on Figure 1-7. Generally all tests are proceeding approximately on schedule with minimal risk to the Apollo-Saturn 201 Mission. Current status of these tests is as follows:

a. S-IVB battleship - Testing for the Saturn IB program has been completed.

b. S-IB-S structural - Propellant tank tests are approximately one month behind schedule. Final test preparation is nearing completion.

c. S-IB-S structures - The fin assembly and tail section assembly have been prepared for test and test procedures completed.

d. S-IU-200/500S structures - The Saturn IB loading for the S-IU 200/500S was completed satisfactorily with no reported failures.

e. S-IU-200V vibration test - Was completed on 31 July 1965. The seven weeks delay in test completion was caused by special tests required to insure the practicability of mechanical fasteners. No effect on Apollo-Saturn 201 Mission will result from this delay.

f. S-IB-D dynamic - Additional dynamic tests are in process with the S-IVB-D and S-IU-200D units. Completion is scheduled for mid-September.

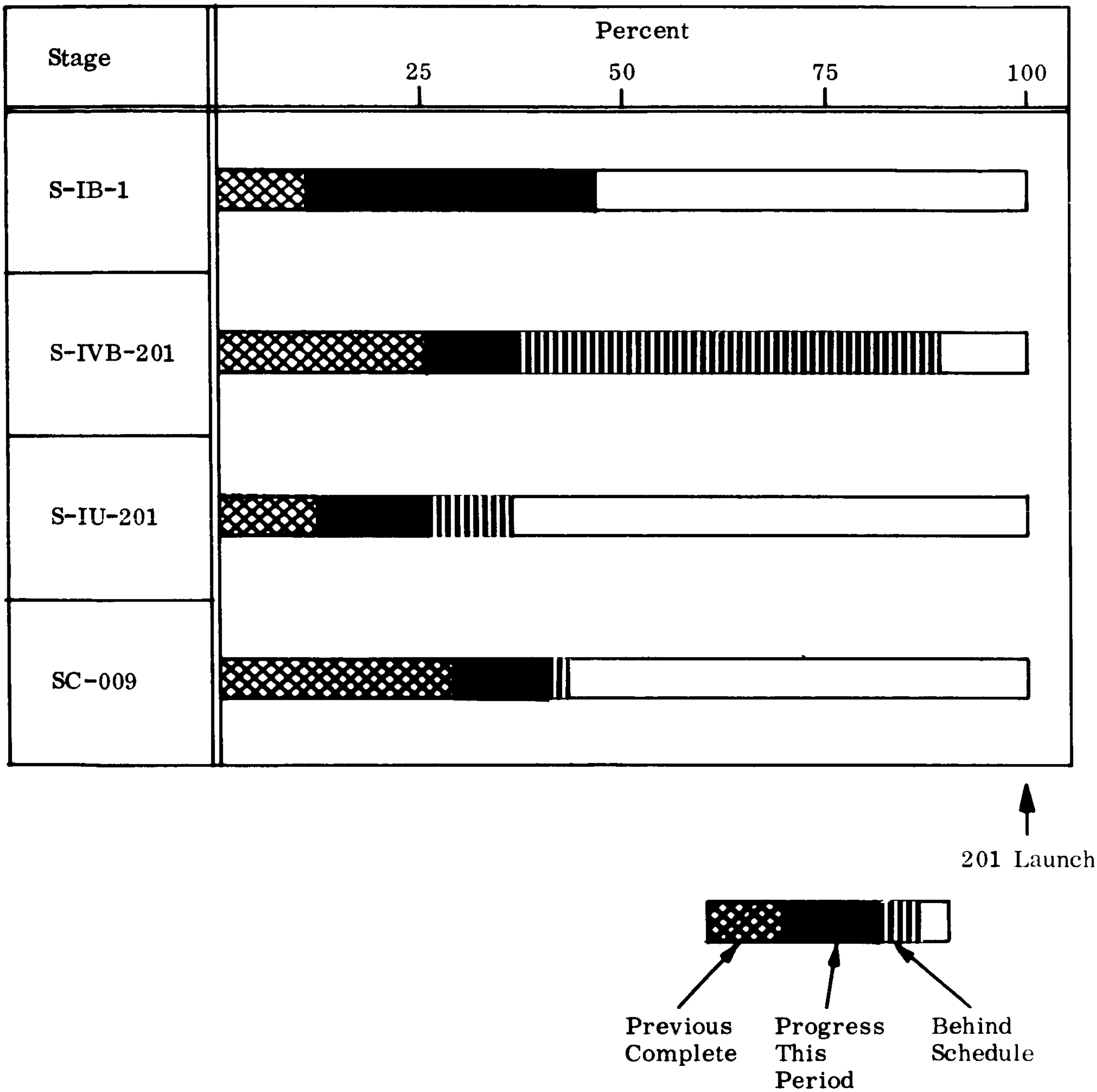


Figure 1-6. Apollo-Saturn 201 Component Qualification Status

[redacted]

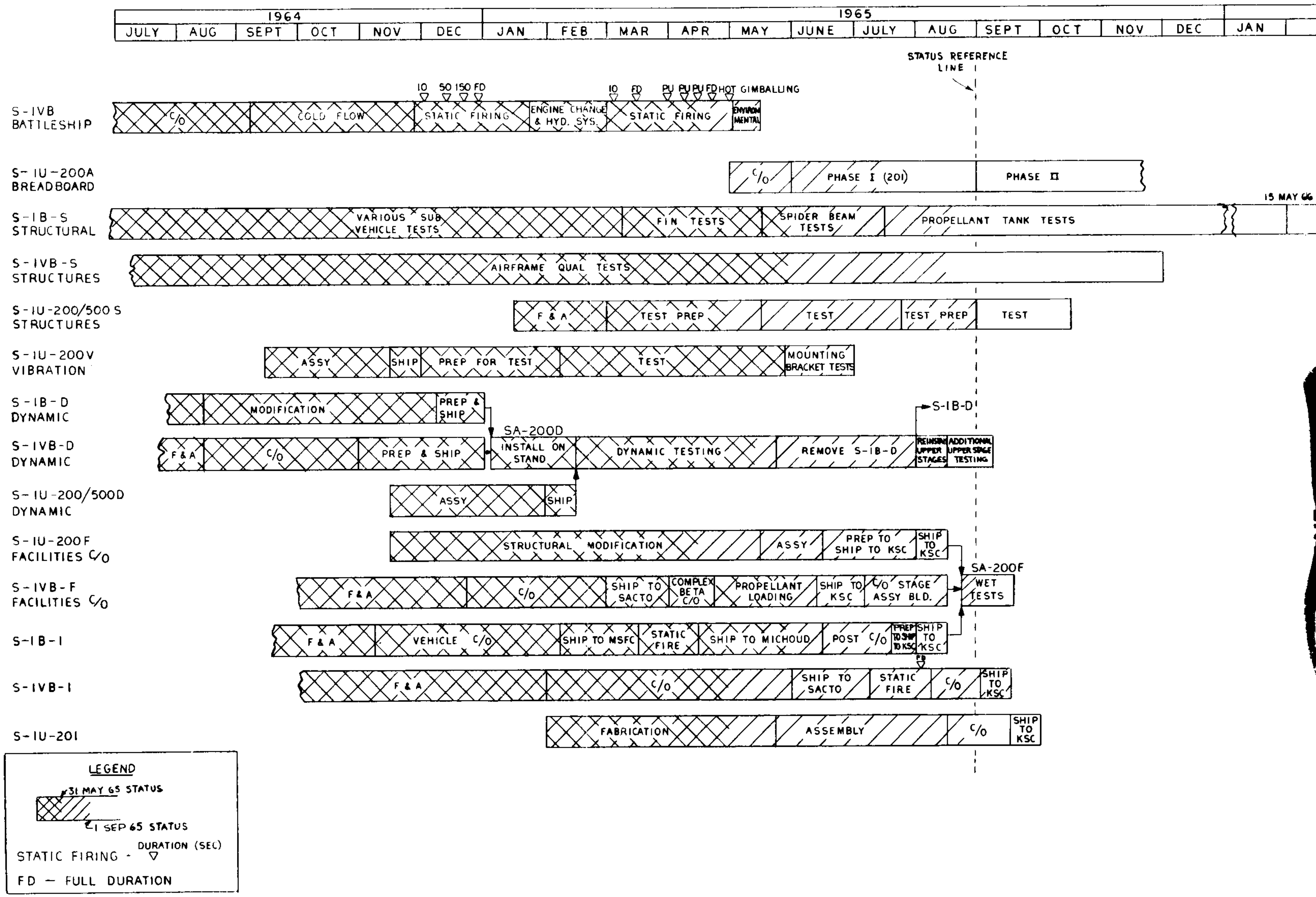


Figure 1-7. Supporting Ground Tests: Launch Vehicles Apollo-Saturn 201, 202, 203 Missions

[redacted]

[redacted]

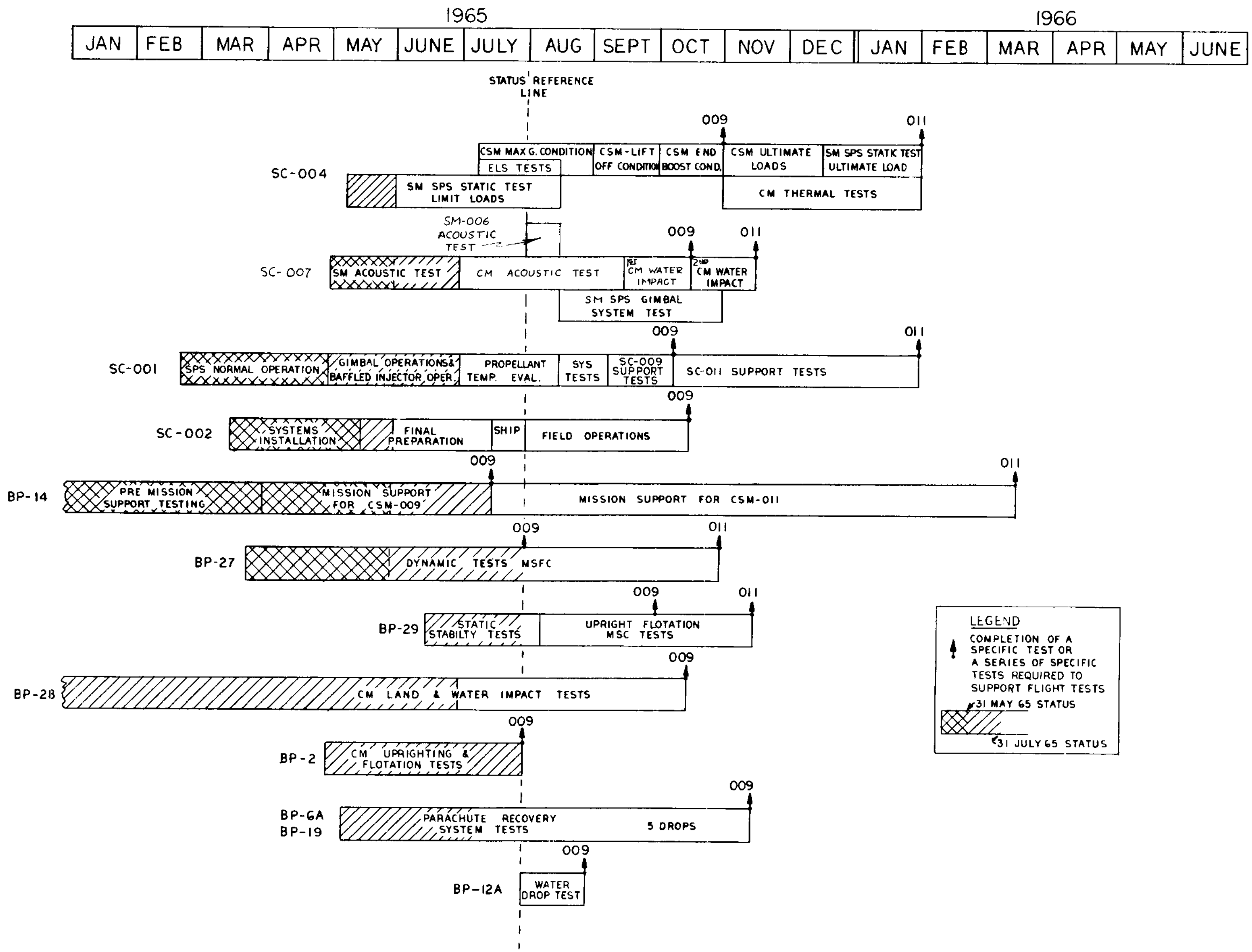


Figure 1-7. Supporting Ground Tests: SC-009 & SC-011 Apollo-Saturn 201, 202 Missions (Cont.)

[redacted]

[redacted]

g. The S-IU-200F, S-IVB-F, and S-IB-1 stages have been stacked with the Spacecraft Verification Vehicle at LC 34. Propulsion subsystems checkout, blockmeter calibration, and DDAS test are being performed as part of the wet test sequence. During the leak test of the instrument compartment (atop the fuel tank dome) an overpressurization occurred causing the tank dome to depress six inches inward with resultant tears and cracks in the dome material. MSFC is evaluating possible corrective actions.

h. S-IVB-201 has completed checkout and has been shipped to KSC.

i. S-IU-201 is in process of checkout at MSFC. Start of this test nine days late may cause a slippage of the 4 October delivery date.

j. Mission supporting tests on BP-14 and Command Module uprighting and flotation tests on BP-2 have been completed.

k. Service Module acoustic tests on SC-007 have been completed, but the Command Module acoustic tests (on SC-007) are approximately four weeks behind schedule.

l. Spacecraft 004 CSM static structural tests are several weeks behind schedule.

m. There is an eight week slippage in acceptance test and checkout of SC-009 at Downey. It is presently scheduled for shipment to KSC about 30 September 1965.

n. There appears to be a redundancy of ground test vehicles for Command Module water impact, flotation, and recovery tests.

o. Several CSM subsystems will not complete their formal test program prior to the scheduled launch date of SC-009.

A change in basic test philosophy is evidenced by the emphasis placed on certification test by MSC. The Certification Test Network encompasses all phases of hardware testing including sybsystems test and component qualification.

[redacted]

1.1.3 APOLLO-SATURN 202 MISSION

1.1.3.1 Configuration

Major differences between the Apollo-Saturn 201 and 202 space vehicles occur in the Spacecraft and the Instrument Unit. The Spacecraft on the Apollo-Saturn 202 Mission will carry the guidance and navigation subsystem for the first time and will have batteries replaced by fuel cells. On the Apollo-Saturn 202 Mission, the Emergency Detection System will be flown closed loop in both the Instrument Unit and Spacecraft for the first time.

1.1.3.2 Mission Profile/Mission Objectives

Apollo-Saturn 201 and 202 are nonorbital flights that have similar mission objectives:

a. Launch vehicle development.
b. Compatibility and structural integrity of CSM-Saturn IB.
c. CSM systems development.
d. Heat shield performance during high thermal loading.
e. Mission support facilities operation.

The mission profiles for Apollo-Saturn 201 and 202 are similar except for the type of measurements monitored for CM heat shield, evaluation, and the flight duration and touchdown locations used.

1.1.3.3 Ground Support Test

The supporting ground tests for the Apollo-Saturn 202 Mission are a continuation of those required for Apollo-Saturn 201. A summary of the test status for the SA-202 Launch Vehicle is the same as SA-201. The certification test summary for Spacecraft 011 is shown on Figure 1-8; it indicates 95 certification tests behind schedule.

1.1.3.4 Reliability Prediction

Compilation of predictions supplied by contractors for the Apollo-Saturn 202 Mission has been started. The results of mission success and contingency success computations will be supplied when available.

SC-009 Certification Test Status

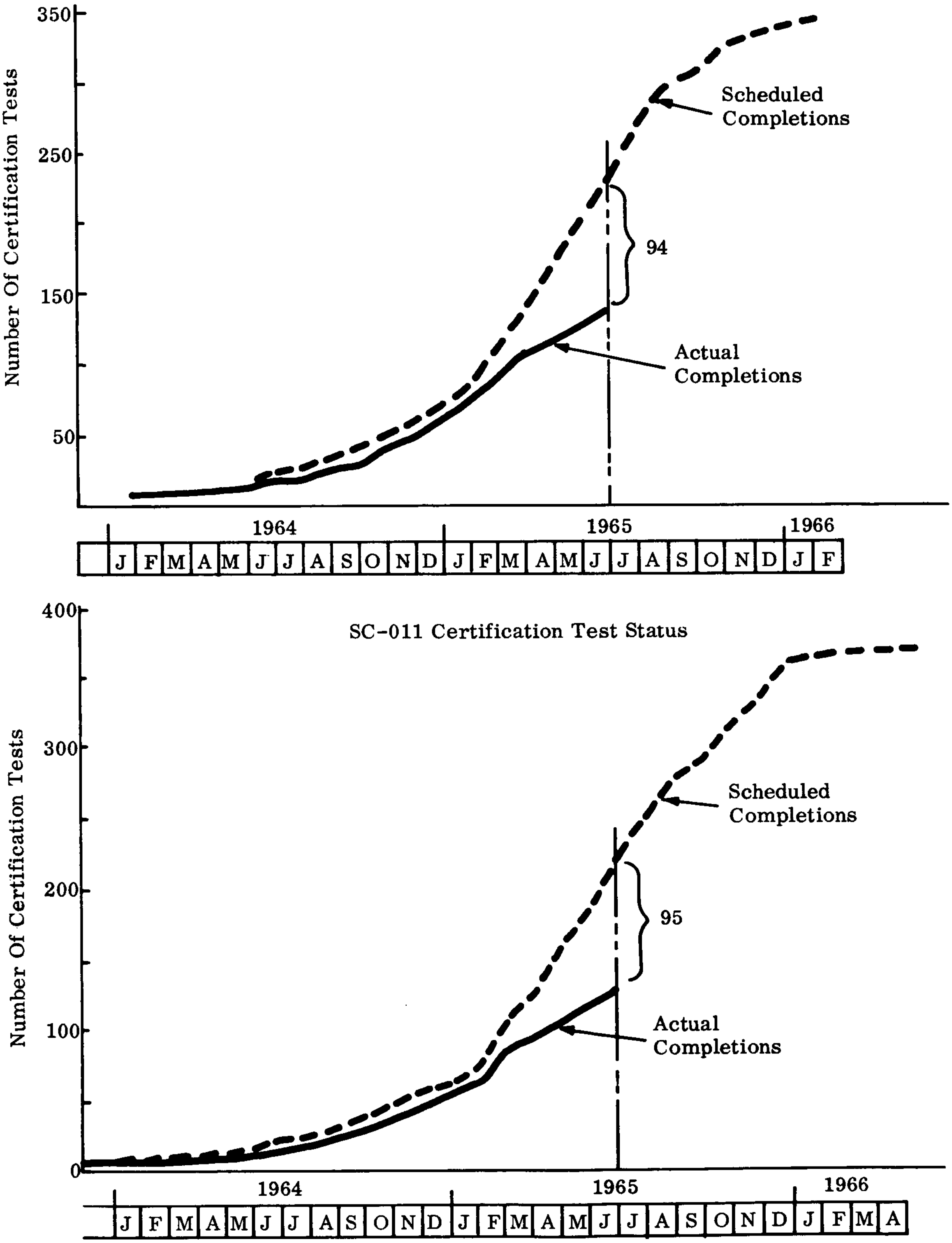


Figure 1-8. SC-009 and SC-011 Certification Test Status

[redacted]

The Apollo-Saturn 202 Mission profile is shown in Figure 1-9 in format similar to that used in Figure 1-2 for the Apollo-Saturn 201 Profile. Although both profiles are for ballistic trajectory, major differences in events and timing occur following the S-IVB cutoff. Since only goals are available for the 200 series of missions (not contractual apportionments), the same breakdown or allocation into subsystems of the stage goals can be assumed for the Apollo-Saturn 202 Mission as was used for the 201 Mission.

1.1.4 APOLLO-SATURN 203 MISSION

1.1.4.1 Configuration

The major differences between the Apollo-Saturn 201 and 203 Mission configurations occur in the S-IB stage. New thin-wall fuel and oxidizer tanks will be flown for the first time on Apollo-Saturn 203. There will be no spacecraft flown on the Apollo-Saturn 203 Misssion.

1.1.4.2 Mission Profile/Mission Objectives

The primary objective of Apollo-Saturn 203 differs from that of the 201 and 202 missions. While Apollo-Saturn 201 and 202 missions are planned to develop the launch vehicle and spacecraft (see paragraph 1.1.3.2), the primary objective of Mission 203 will be the experiment of LH_2 containment in near zero-g environment, checkout of S-IVB and IU in orbit, and mission support facilities operation.

The mission profile for Apollo-Saturn 203 is a 100 nautical-mile circular orbit with no recovery. The Apollo-Saturn 202 Mission Profile calls for a nonorbital super circular re-entry.

The payload of the Apollo-Saturn 203 flight will have a shroud only; whereas, CSM 011 is planned for Mission 202. The S-IVB-203 will be put in orbit with 18,000 pounds of LH_2.

1.1.4.3 Ground Support Test

Ground verification testing for the thin-wall fuel and oxidizer containers has begun approximately one month behind schedule. No problems are forseen for the Apollo-Saturn 203 Mission.

[redacted]

Elapsed Time in Seconds		Events	Normalized Profile		
MSFC Profile (27)	MSC Profile (27)	(A subphase extends from an event to the next event)	Elapsed Time in Seconds	Subphase Number	Subphase Time in Seconds
		Start Countdown			
				1	---
0.00	0.00	Liftoff, Hold Down Release	0.00		
				2	146.25
146.25		S-IB Cutoff	146.25		
				3	5.50
151.75		S-IVB Full Thrust	151.75		
				4	20.00
171.75		LES Jettison	171.75		
				5	438.20
609.95	609.95	S-IVB Engine Cutoff	609.95		
				6	10.00
	619.95	S-IVB/IU/SLA CSM Separation and RCS Ullage	619.95		
				7	11.00
	630.95	SPS First Ignition	630.95		
				8	233.86
	864.81	SPS First Cutoff	864.81		
				9	3133.67
	3998.48	Coast and Orientation Maneuver and RCS Ullage	3998.48		
				10	30.00
	4028.48	SPS Second Ignition	4028.48		
				11	84.97
	4113.45	SPS Second Cutoff	4113.45		
				12	10.00
	4123.45	SPS Third Ignition	4123.45		
				13	3.00
	4126.45	SPS Third Cutoff	4126.45		
				14	10.00
	4136.45	SPS Fourth Ignition	4136.45		
				15	3.00
	4139.45	SPS Fourth Cutoff	4139.45		
				16	143.69
	4283.14	CM/SM Separation	4283.14		
				17	5.00
	4288.14	Begin Entry Orientation	4288.14		
				18	113.79
	4401.93	Entry	4401.93		
				19	72.00
	4473.93	0.05 g	4473.93		
				20	767.59
	5241.52	Tow. & Apex Cover Jet.	5241.52		
				21	406.34
	5647.86	Touchdown	5647.86		

Figure 1-9. Apollo-Saturn 202 Mission Profile

1.2 S-IB STAGE

1.2.1 GENERAL

1.2.1.1 Milestones

Milestones necessary to monitor the S-IB Stage Reliability and Quality Assurance program are shown in Figure 1-10. In general, the documentation identified in the milestones provides the data required to establish the S-IB Stage Reliability and Quality Assurance Status. Major accomplishments during the third quarter of 1965 were as follows:

a. Delivery and errection of the S-IB Stage on Launch Complex 34 at KSC for use as a facilities checkout vehicle.
b. Delivery to MSFC of the S-IB-2 Stage for static firing tests.

The two problems identified in the second quarter status report have been resolved as follows:

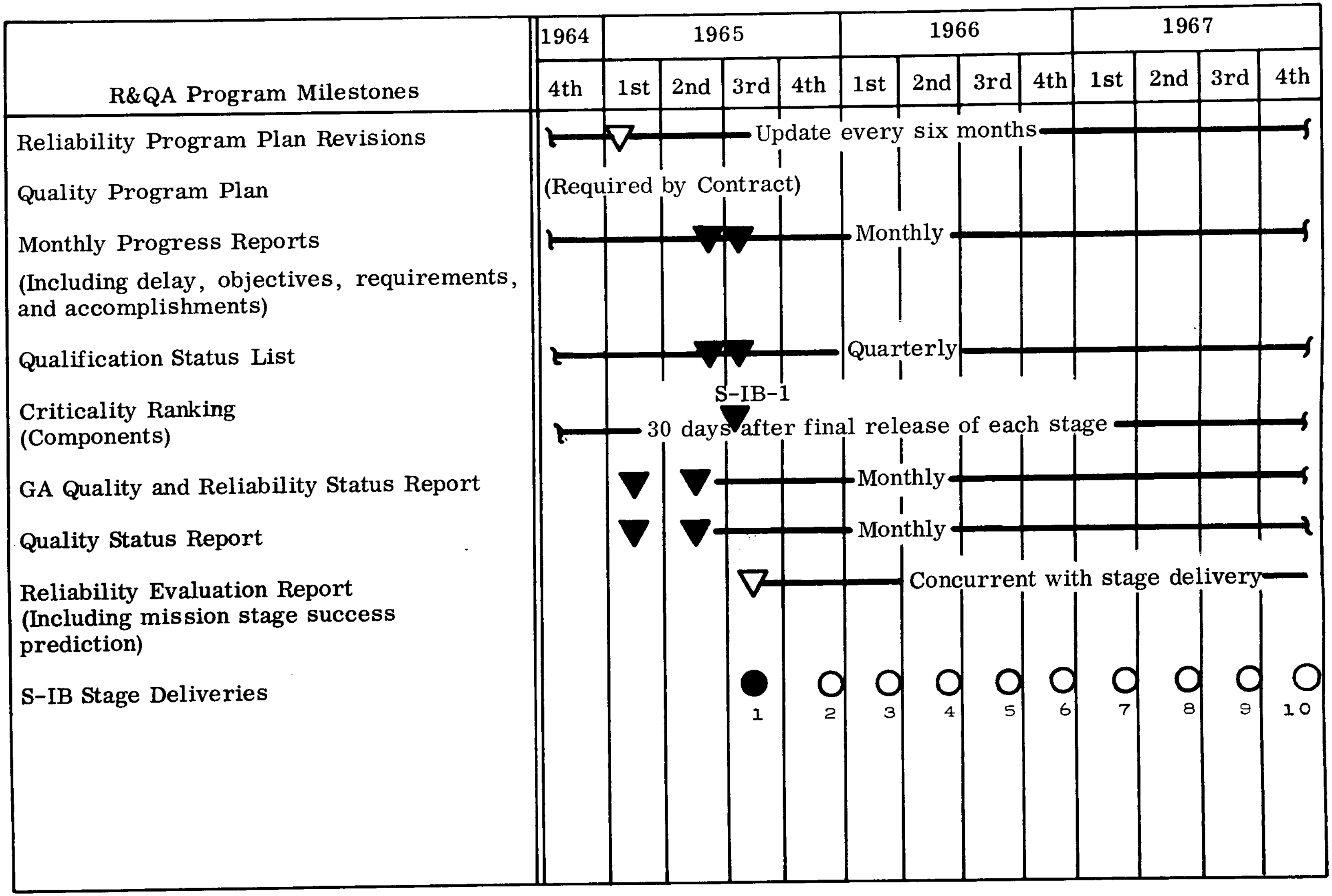
a. Spider beam failure - Modified channel section verified by completion of S-IB dynamic test.
b. Split engine tubes - Attributed to decreased stress margins as a result of thrust chamber upratings. A program is under way at Rocketdyne to improve the thrust chamber by increasing the stress margin through the use of a longer jacket prefill as a deterrent to upper combustion zone tube burning.

1.2.1.2 Reliability Program

A reliability assurance evaluation was performed by MSFC on the S-IB Stage. The evaluation compared the degree that NPC 250-1 reliability elements were contractually required and the degree to which they have been implemented (see Figure 1-11).

Specific recommendations for further enhancing the Chrysler Corporation Space Division (CCSD) Reliability Program have been forwarded to program management.

[redacted]



KEY:

Scheduled: Software ▽ Hardware ○

Completed: Software ▼ Hardware ●

Figure 1-10. S-IB Stage - Reliability and Quality Assurance Milestones

[redacted]

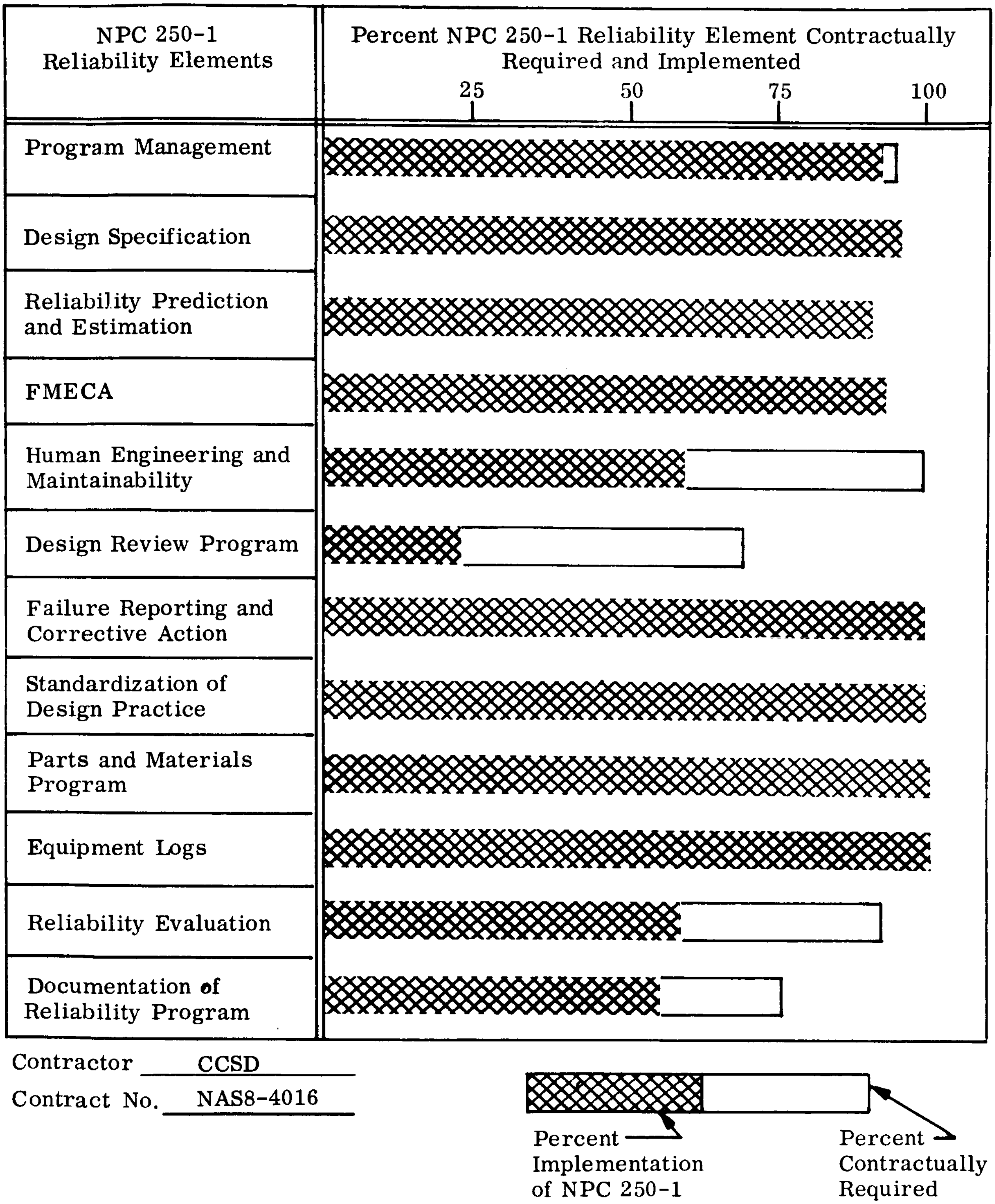


Figure 1-11. S-IB Stage Reliability Assurance Evaluation Based on NPC 250-1

A reliability program plan for the H-1 Engine is being prepared by Rocketdyne as part of contract conversion to incentive type. The plan will basically satisfy the requirements of NPC 250-1. A Reliability Assurance Evaluation Report will not be prepared for the H-1 engine program due to the production status of the engine.

1.2.2 RELIABILITY ENGINEERING

1.2.2.1 Design

During the reporting period, functional reliability drawings for the S-IB-3 Stage and the preliminary critical items test for the S-IB-4 Stage were completed.

Initial issue of the S-IB-3 Malfunction Detection System (MDS) Design Analysis was distributed in July.

1.2.2.2 Redundancy and Trade-off Studies

Findings of an investigation of the present routing of the LOX bubbling line were issued in a Human Factors/Maintainability report by CCSD. Rerouting to avoid human damage possibilities will be effective on S-IB-4.

1.2.2.3 FMECA

A final failure mode and effect analysis was performed on the S-IB-1 Stage by CCSD. Those items, the single failure of which will result in a probability of vehicle loss, are entered on the critical items list in descending order. The ten most critical items as a result of this analysis are shown on Figure 1-12.

A brief failure effect analysis was performed on the 200,000 pound thrust configuration H-1 Engine. A more comprehensive analysis is being conducted on the 205,000 pound thrust program. An H-1 Engine component criticality ranking has been started using the engine failure effects analysis as a basis.

1.2.2.4 Mathematical Models

During the reporting period, CCSD completed the failure rates and logic for use in the S-IB-2 reliability evaluation model and an appendix to the S-IB-1 reliability evaluation

[redacted]

Item	Subsystem	Critical Ranking by Flight Stage			
		S-IB-1			
Gas Turbine	H-1 Engine	1			
Switch Selector Assembly	Sequencing	2			
Feedback Transducer	H-1 Engine Hydraulic	3			
G.G. Control Valve	H-1 Engine	4			
Servo Valve	H-1 Engine Hydraulic	5			
Prevalve Control Valve	H-1 Engine	6			
Turbo Pump and Gearbox Assembly	H-1 Engine	7			
LOX Replenishing Valve	LOX Fill, Drain and Replenish	8			
Regulator	Control Pressure	9			
LOX Fill and Drain Valve	LOX Fill, Drain and Replenish	10			
	REF.	66			

Items Dropped from Preceding List:

Rank	Item

Figure 1-12. S-IB Stage Ten Most Critical Items

[redacted]

model and an appendix to the S-IB-1 reliability model report. This appendix added the summary of range safety, tracking, and telemetry systems reliability evaluation formerly omitted from the report.

1.2.2.5 Goals and Predictions

A trend of mission success predictions in relation to the goal for the S-IB Stage is displayed on Figure 1-13.

The H-1 Engine reliability trend is plotted on Figure 1-14. Engine reliability is based on the last 100 equivalent full duration tests.

1.2.3 TEST PROGRAM

1.2.3.1 Ground Support Test

The spider beam assembly has been qualified. The S-IB-1 Stage is being used as a facility checkout vehicle in support of the wet tests for Launch Complex 34.

During August, 15 failures have been identified on the S-IB-1 Stage bringing the total failures to 212 since the manufacturing checkout. The chart on Figure 1-15 indicates that of these 212 failures, control action is pending on a total of 51 to preclude recurrence on subsequent S-IB stages.

1.2.3.2 Qualification Test

Figure 1-16 shows the total component qualification status for the S-IB-1 stage. This effort is ahead of schedule.

1.2.4 QUALITY ASSURANCE

Figure 1-17 shows the trend in quality rating of the Chrysler Corporation Space Division (S-I/IB). The rating is based on the number and severity of defects and is a function of standard manufacturing hours paid. A rating of 100 indicates no defects for the reporting period. Of the reported defects, 85 percent were attributed to workmanship in the April to May period and 65 percent in the 24 May to 20 June period.

[redacted]

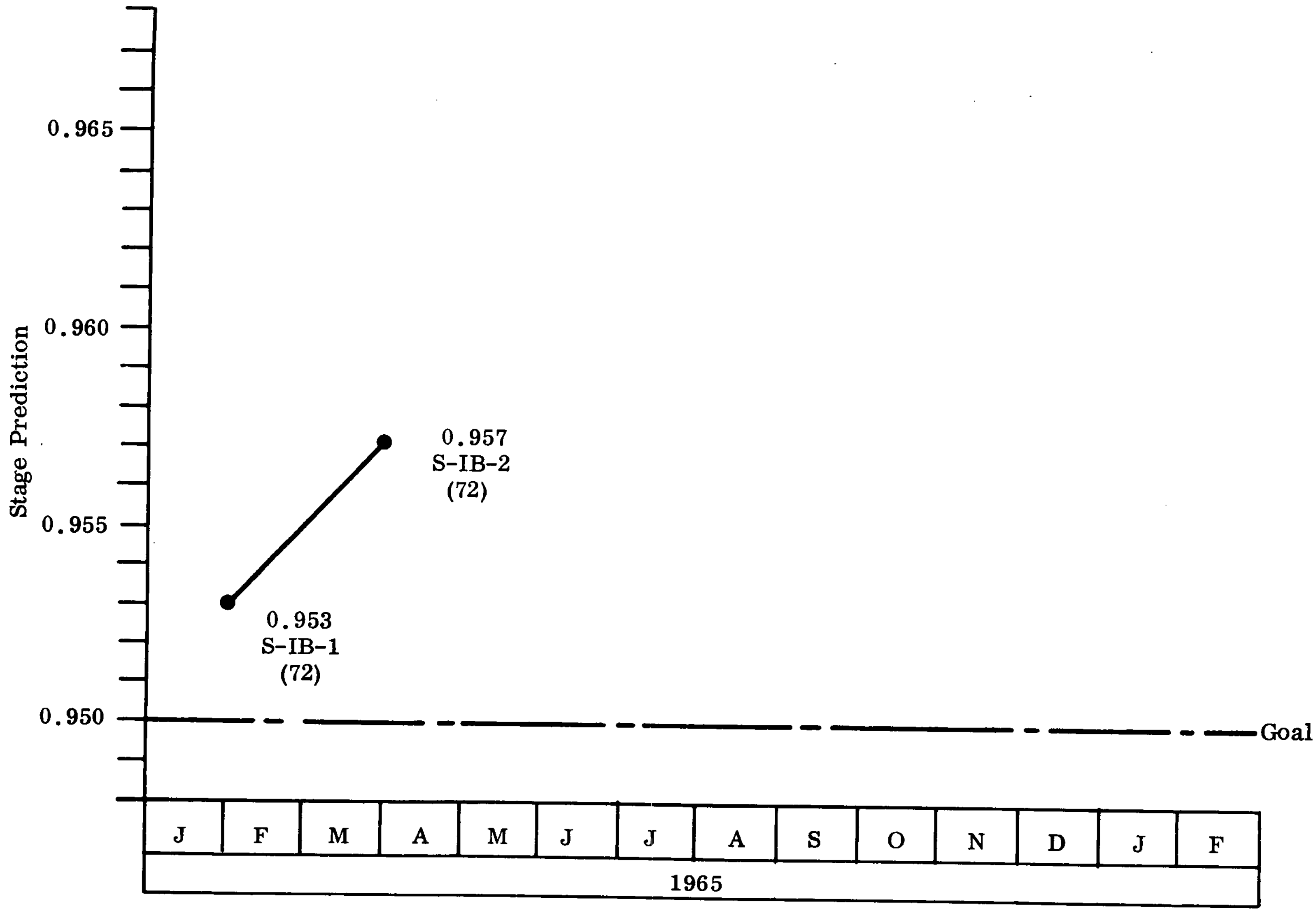


Figure 1-13. S-IB Stage Reliability Trend (Mission Success)

[redacted]

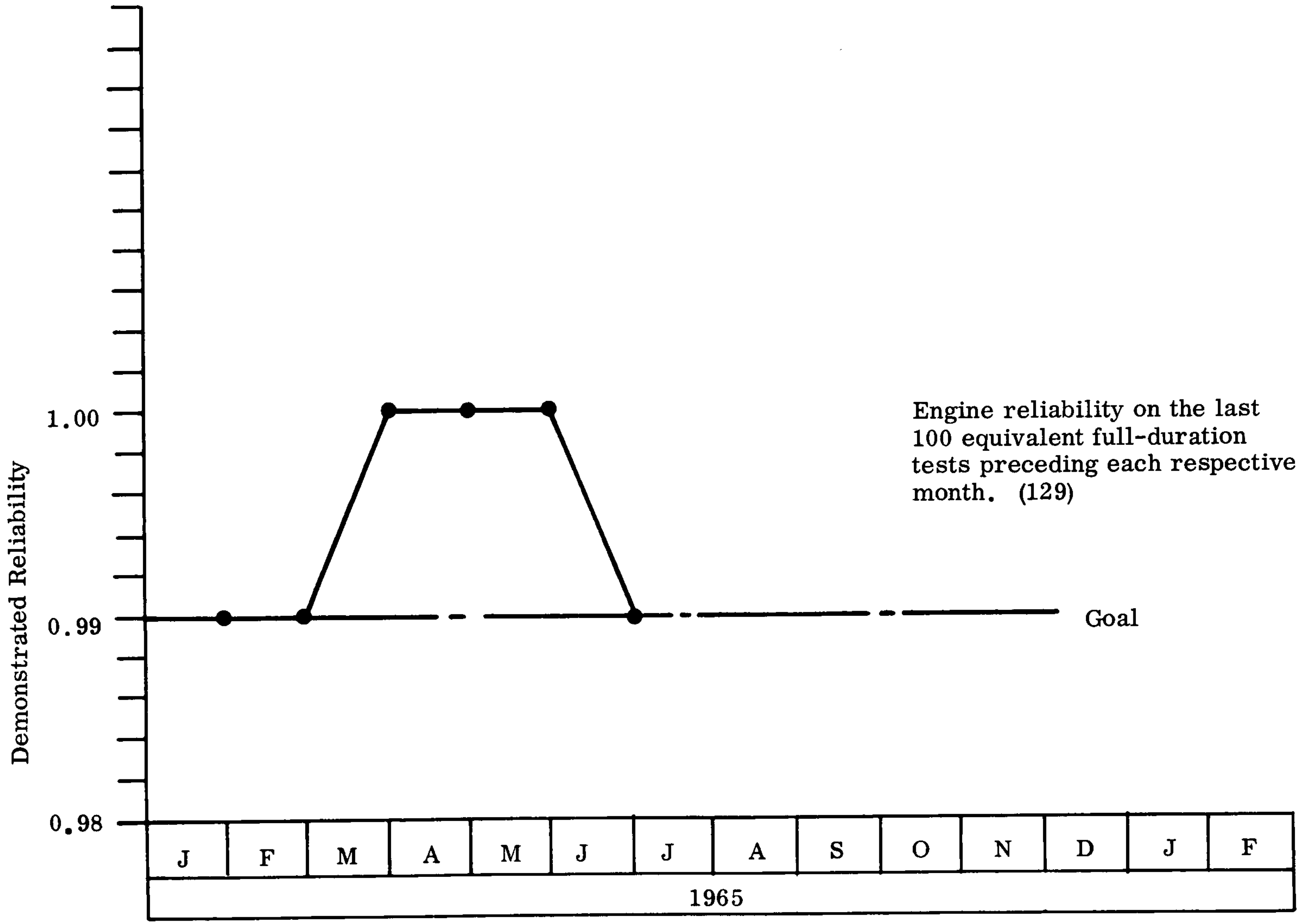


Figure 1-14. H-1 Engine Reliability Trend

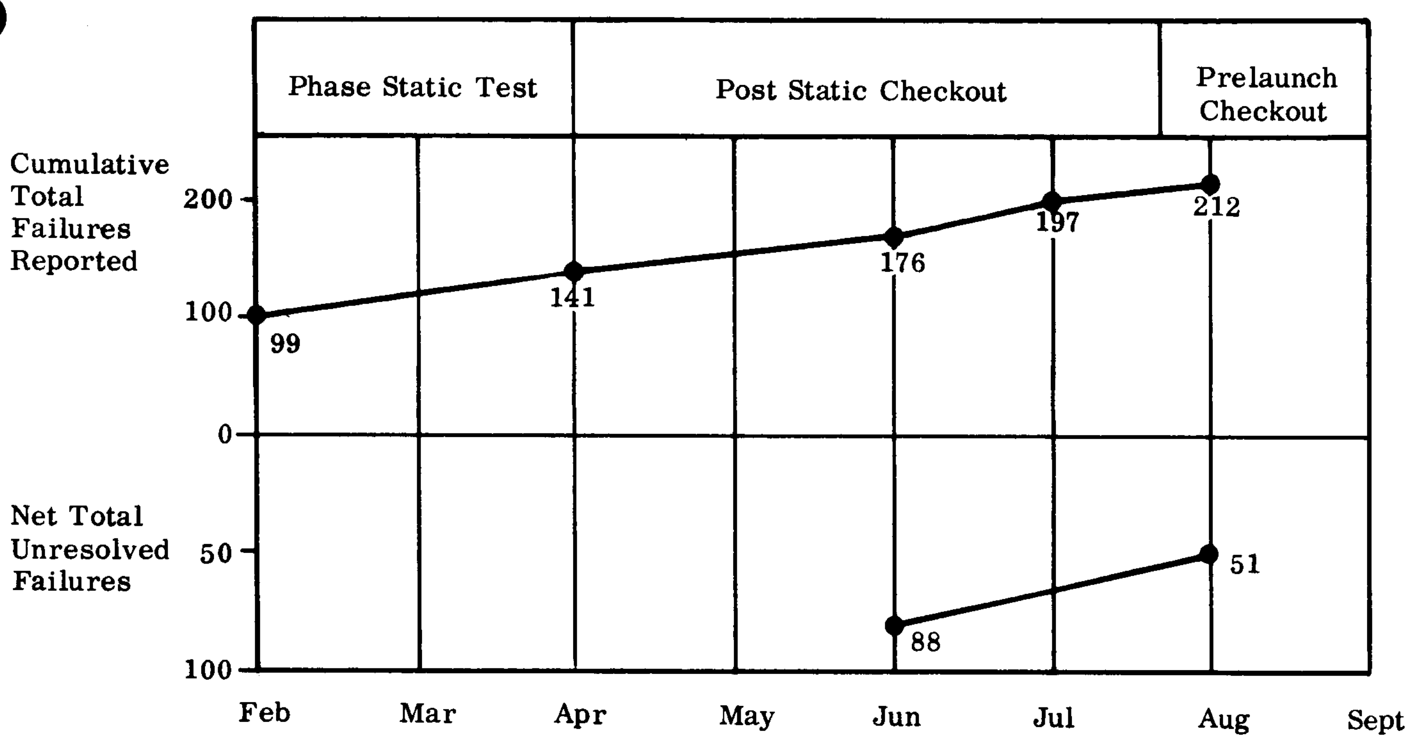


Figure 1-15. S-IB-1 Stage Failure Trend

Figure 1-18 shows the "Unsatisfactory Condition Report" status for S-IB-1 as of 18 June 1965.

1.3 S-IVB STAGE

1.3.1 GENERAL

1.3.1.1 Milestones

Milestones necessary to monitor the S-IVB Stage reliability and quality assurance program are shown in Figure 1-19. In general, the documentation identified in the milestones provides the data required to establish the S-IVB Stage reliability and quality status.

Major accomplishments during the reporting period include the following:

a. Completion of the reliability math models for the S-IVB-202 and the S-IVB 203 Stage.

b. Completion of the S-IB/S-IVB battleship test.

c. Delivery of the S-IVB-201 Stage to KSC.

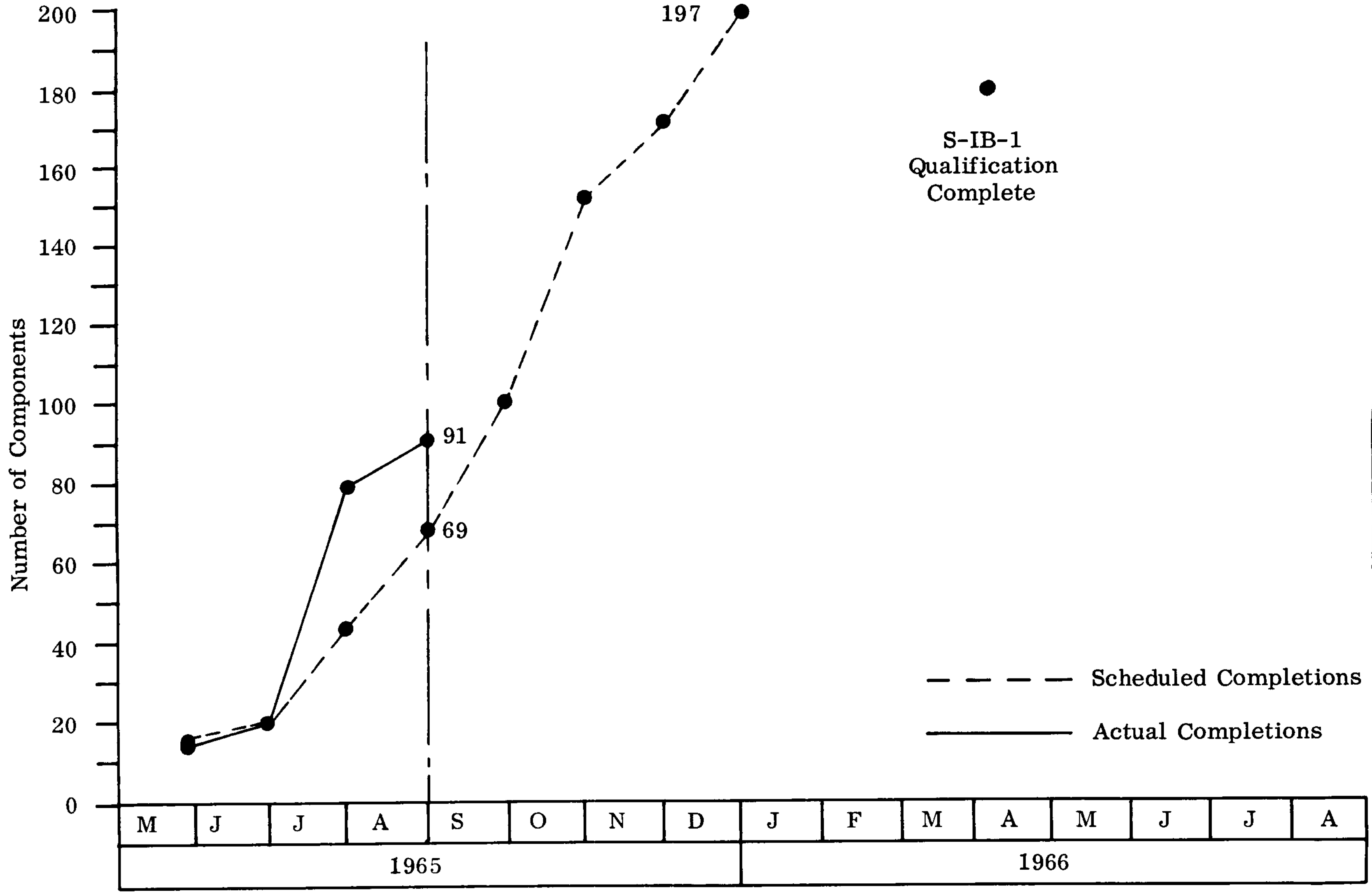


Figure 1-16. S-IB-1 Total Component Qualification

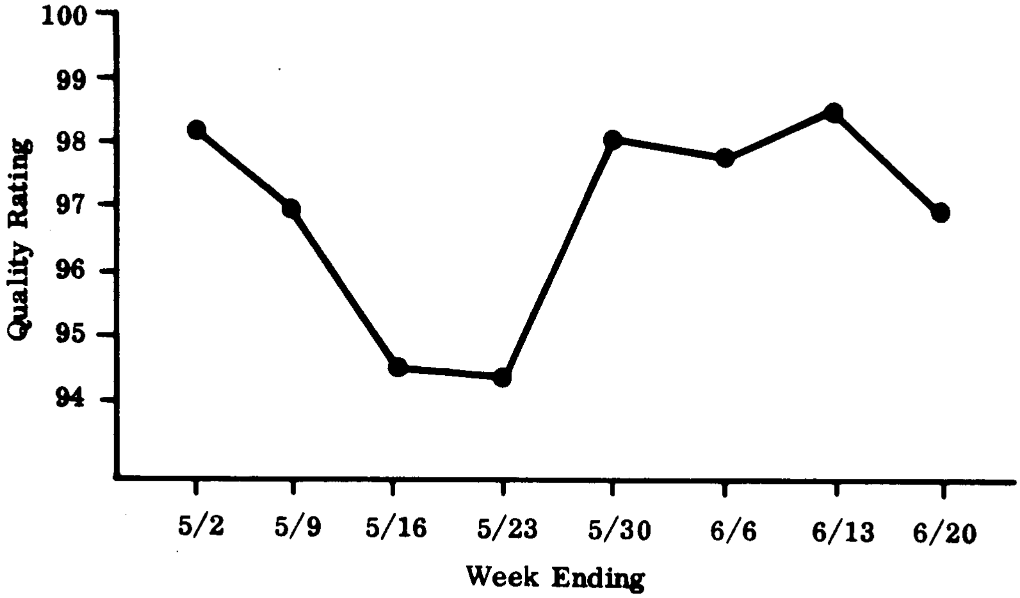
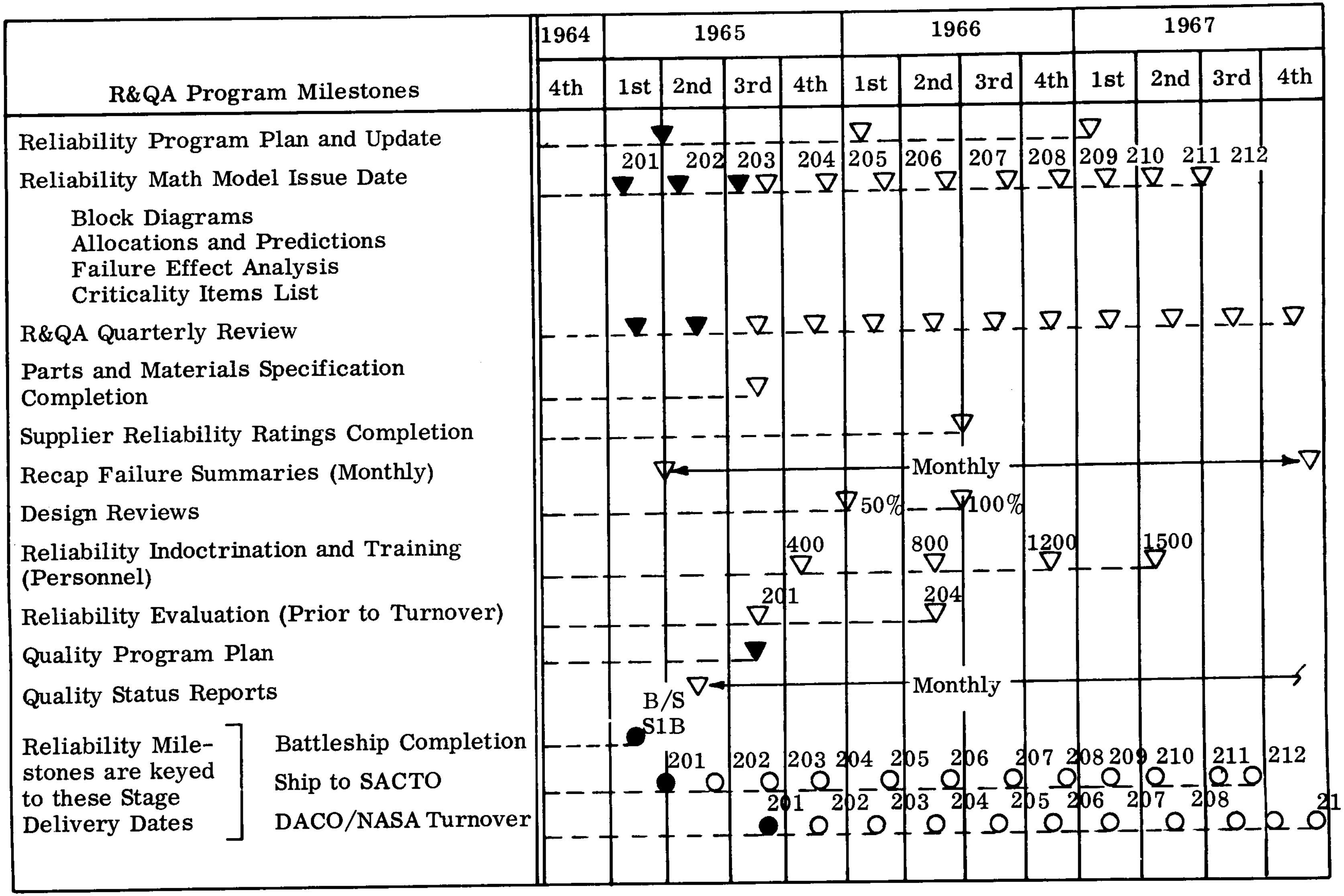


Figure 1-17. CCSD Quality Ratings

Status	Jun	Jul	Aug	Sept
Written	80			
Cancelled	1			
Cleared	23			
Outstanding	56			

Figure 1-18. UCR Status

[redacted]



KEY:

Scheduled: Software ▽ Hardware ○

Completed: Software ▼ Hardware ●

Figure 1-19. S-IVB-IB Stage Reliability and Quality Assurance Milestones

[redacted]

[redacted]

1.3.1.2 Reliability Program

MSFC performs Reliability Assurance Evaluation surveys to determine the degree that contractors are implementing contractually required elements of NPC 250-1.

Figure 1-20 shows the status of the S-IVB Reliability program through 9 September 1965. Figure 1-21 shows the status of the J-2 Reliability program through 9 August 1965.

Reliability assurance evaluation survey formats [I-V Form Number 5, Rev. 15 June 1965 (OT)] have been undergoing a period of development. Therefore, survey results show an irregular pattern of implementation, and no attempt will be made to show the correlation between surveys until the next quarterly status report.

Recommendations for improving the data feedback have been transmitted to project management.

1.3.2 RELIABILITY ENGINEERING

1.3.2.1 Design

The S-IVB Quarterly Review was held at Douglas Aircraft Company, Inc. (DAC), Huntington Beach, California, 15 September 1965.

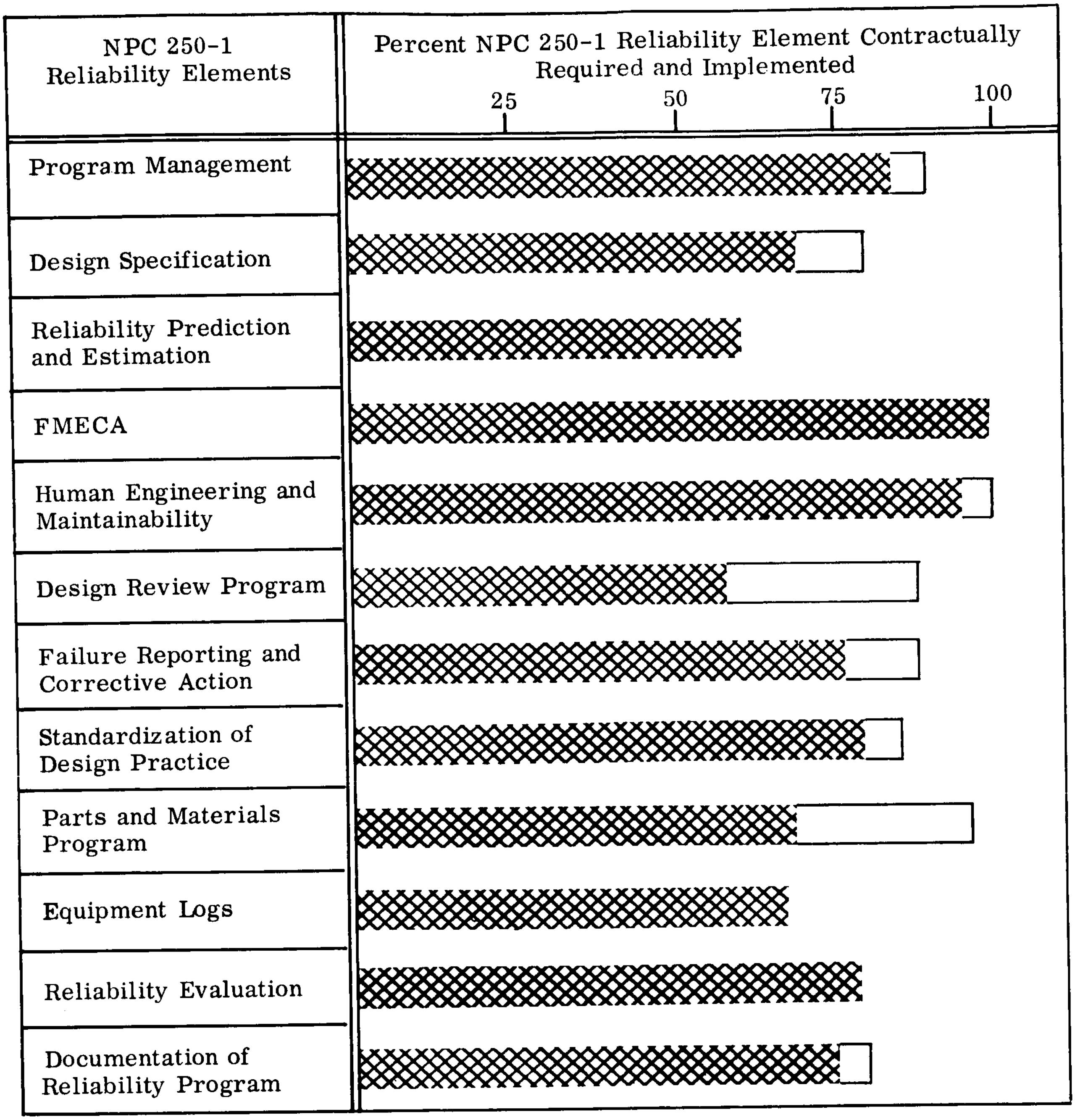
1.3.2.2 Redundancy and Trade-off Studies

A structural defect in the manhole cover area at the tank ends was discovered in the S-IVB battleship test under certain critical load conditions. An analysis of this problem concluded that reinforcement would be added at KSC on the S-IVB-201 Stage by bonding metal strips around the collar weld area.

1.3.2.3 FMECA

The S-IVB-201 Failure Effects Analysis (FEA) was conducted by Douglas in March 1965. Critical items were identified using the MSFC Critical Ranking Technique. The S-IVB-202 FEA and critical items list were completed in May 1965, and the S-IVB-203 was completed in August 1965. Release of the S-IVB-204 Stage model is scheduled for the first week of November 1965.

[redacted]



Contractor Douglas Aircraft Co.

Contract No. NAS 7-101

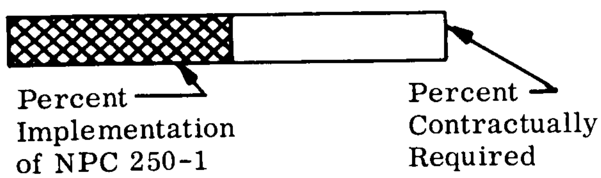


Figure 1-20. S-IVB Stage Reliability Assurance Evaluation Based on NPC 250-1

[redacted]

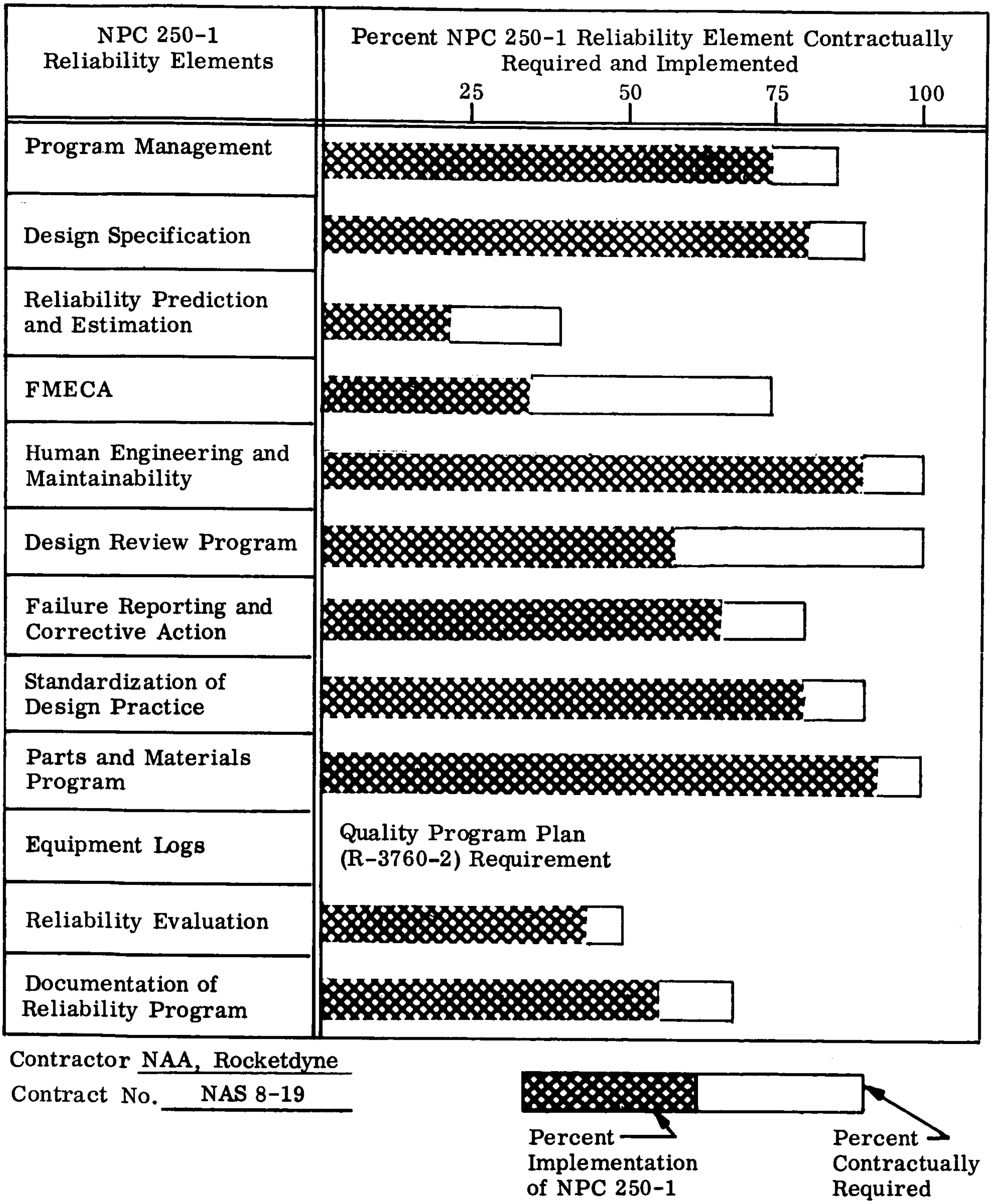


Figure 1-21. J-2 Engine Reliability Assurance Evaluation Based on NPC 250-1

[redacted]

The S-IVB-202 Math Model incorporates 17 Engineering Change Proposals (ECP's) and Scope Changes (SC's) that are not in the S-IVB-201 configuration. The results of these changes are the basis for a new list of the ten most critical items as shown on Figure 1-22.

1.3.2.4 Mathematical Models

A math model will be issued for each S-IVB Flight Stage in the Saturn IB program. The prediction for S-IVB-201 is 0.966. The prediction for S-IVB-202 is 0.97. The increased reliability prediction reflects the incorporation of the 17 proposed design changes in the S-IVB-202 Failure Effects Analysis.

1.3.2.5 Apportionments and Predictions

The reliability trend for the S-IVB stage is illustrated in Figure 1-23.

1.3.3 TEST PROGRAM

1.3.3.1 Ground Support Test

S-IVB-201 full duration 455-second acceptance firing was successfully completed on 8 August. The S-IVB-201 departure date for KSC slipped from 28 August to 3 September. S-IVB-20 arrived at KSC 19 September 1965.

No failures were reported on the S-IVB-201 Stage during the reporting period. Figure 1-24 indicates the failure and control action trend from post manufacturing checkout through this quarter's activity.

1.3.3.2 Qualification Test

The S-IVB formal qualification test program has been delayed by failures occurring in the development qualification phase of the test program. These development qualification tests are considered by the contractor as prerequisites for the release of hardware configuration to formal qualification.

[redacted]

Item	Subsystem	Critical Ranking by Flight Stage			
		S-IVB201	S-IVB202		
J-2 Engine (GFE)	Thrust	2	1		
Switch Selector	Electrical Control	1	2		
Motor, Retro Rocket	Lower Stage Reverse Thrust	22	3		
Actuator Assembly, Hydraulic	Hydraulic	5	4		
Sequencer Mounting Assembly	Electrical Control	4	5		
Module Activation Control	Pneumatic Control	7	6		
Hydraulic Pump	Hydraulic	18	7		
Power Distribution Mounting Assembly AFT 28 VDC	Electrical Control	10	8		
Valve, Propellant Tank Shutoff	LH_2 Feed and Chilldown	12	9		
Pump Hydraulic, Auxiliary Motor Driven	Hydraulic	9	10		
	REF.	76	77		

Items Dropped from Preceding List:

Rank	Item
3	Electrical Distribution
6	Attitude Control Relay
8	Module Low Pressure Helium

Figure 1-22. S-IVB Stage Ten Most Critical Items

[redacted]

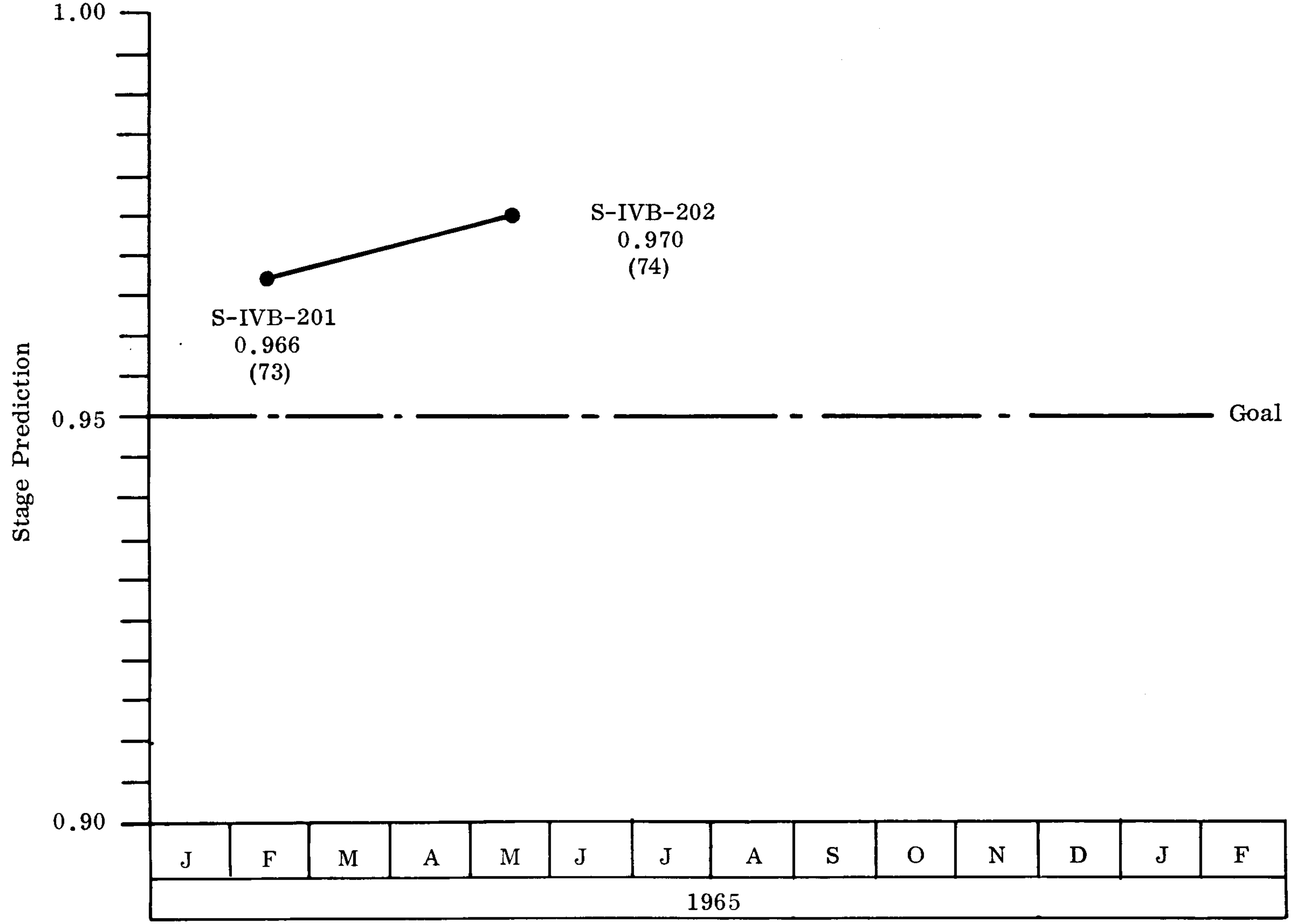


Figure 1-23. S-IVB Stage Reliability Trend (Mission Success)

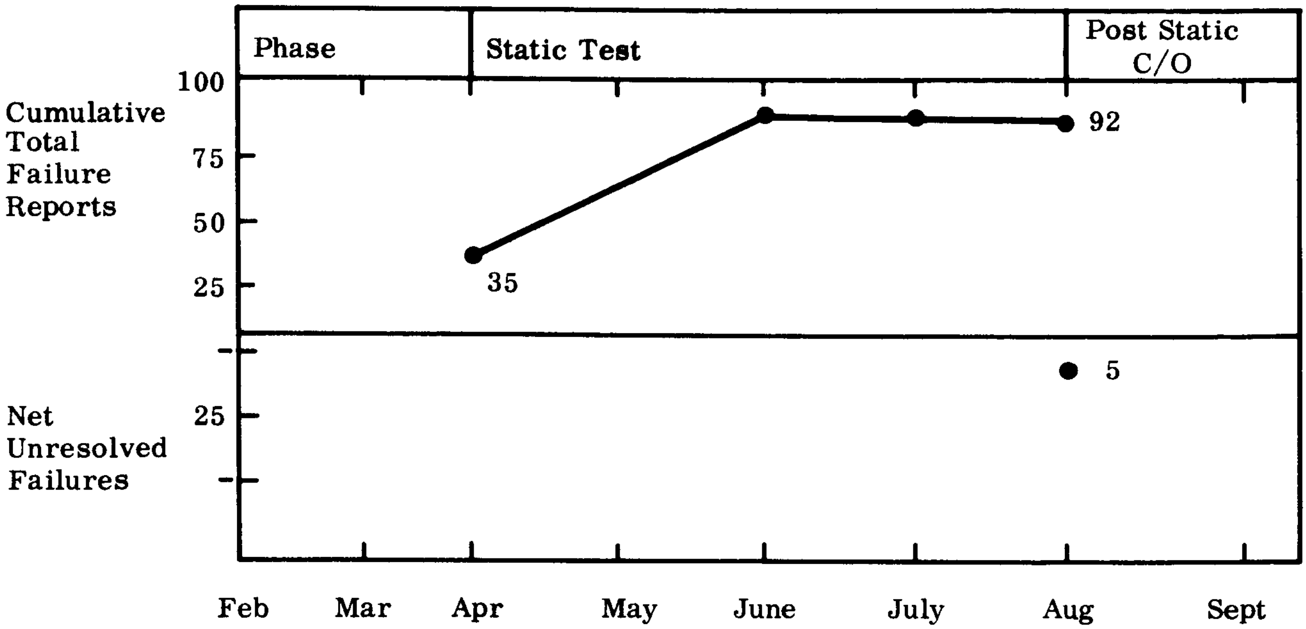


Figure 1-24. S-IVB-201 Failure Trend

Based on present analysis, the formal qualification tests are not expected to be complete before the latter part of March 1966 instead of 15 October 1965 as scheduled.

The component qualification status is shown in Figure 1-25.

1.3.4 QUALITY ASSURANCE

Figure 1-26 shows the trend in percent parts discrepant at final assembly of the J-2 Engines.

Figure 1-27 shows the discrepancies detected at Electrical and Mechanical (E&M) Inspection on the indicated J-2 Engines. This includes both pre- and post-firing E&M Inspection.

Figure 1-28 shows the trend in the total number of Failure and Rejection Reports (FARR's) per month written by the contractor.

[redacted]

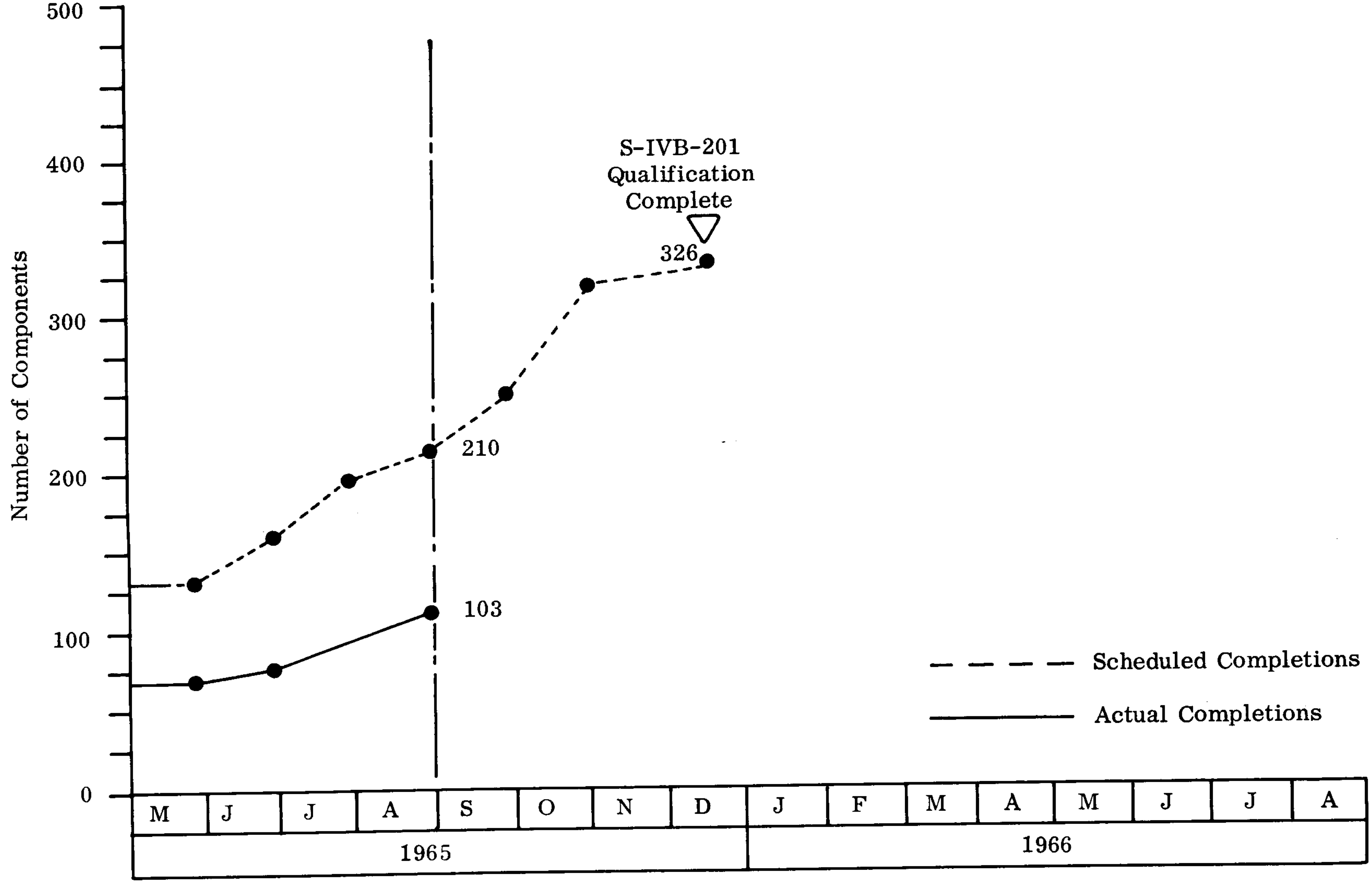


Figure 1-25. S-IVB-201 Total Component Qualification

[redacted]

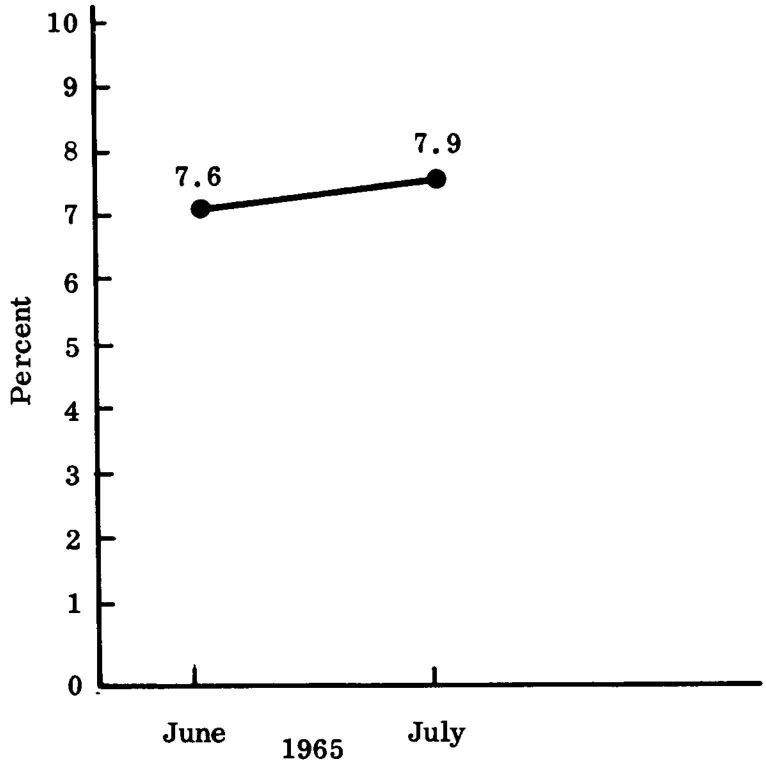


Figure 1-26. J-2 Engine Percent of Parts Discrepant at Final Assembly

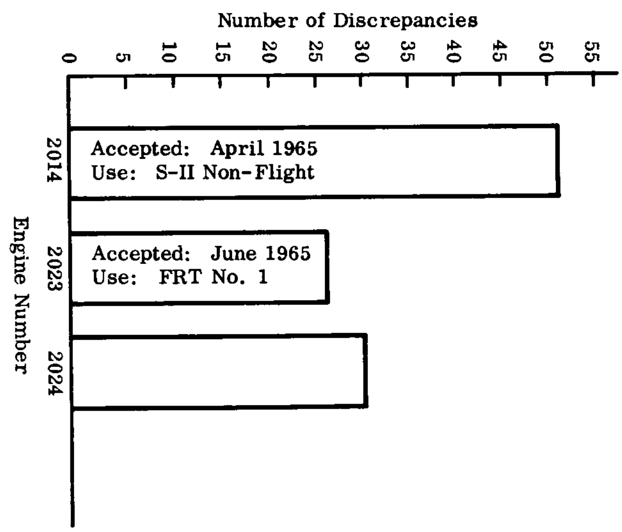


Figure 1-27. J-2 Engine Discrepancies/Malfunctions (Failures) at Electrical and Mechanical Inspections

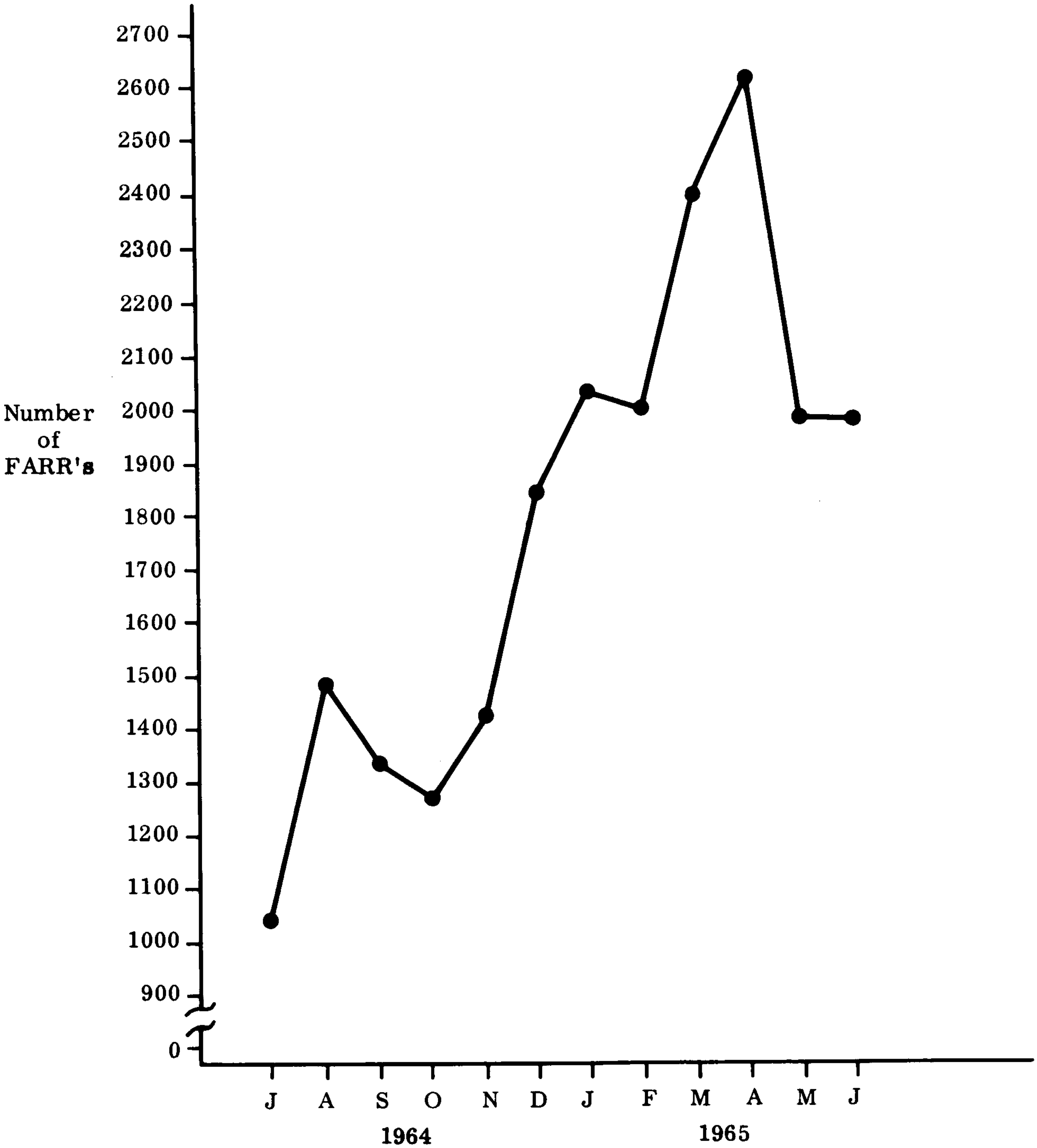


Figure 1-28. S-IVB Stage Failure and Rejection Reports

1.4 S-IU STAGE

1.4.1 GENERAL

1.4.1.1 Milestones

Milestones necessary to monitor the S-IU Stage Reliability and Quality Assurance program are shown in Figure 1-29. In general, the documentation identified in the milestones provides the data required to establish the S-IU Stage Reliability and Quality Assurance status.

ESE (IU) availability slipped from mid-April to mid-August 1965, and the IU checkout start from early June to late August 1965. The S-IU-201 began electrical checkout on 29 August 1965, which may jeopardize the 4 October 1965 delivery data to KSC.

IBM Owego is currently scheduled to deliver the LVDC and LVDA for S-IU-201 18 September 1965. The effect of this one month delivery slip is under assessment.

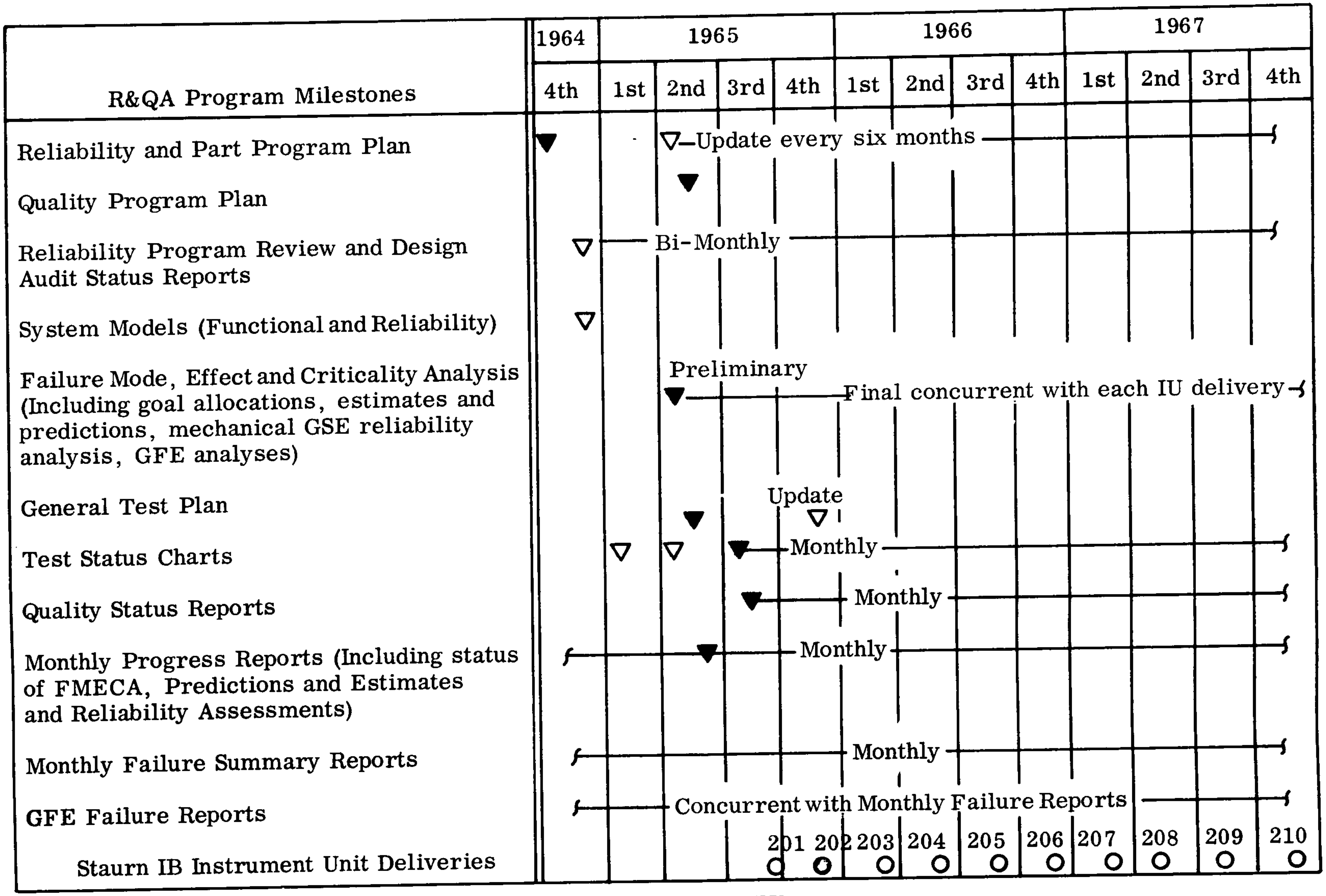
Status of problems reported last quarter is as follows:

a. Investigation of the S-IU-200V mounting bracket problem has resulted in moving and redesigning the brackets. Resulting schedule changes are under evaluation.

b. Structure components qualification test completion dates have been rescheduled to offset the slippage uncovered during the last quarter. No effect on S-IU-201 is anticipated.

1.4.1.2 Reliability Program

MSFC conducted a reliability assurance evaluation on three Instrument Unit contractors during September. The results are shown in Figure 1-30. These evaluations, against NPC 250-1, disclosed a general lack of documentation or insufficient content in the documentation available.

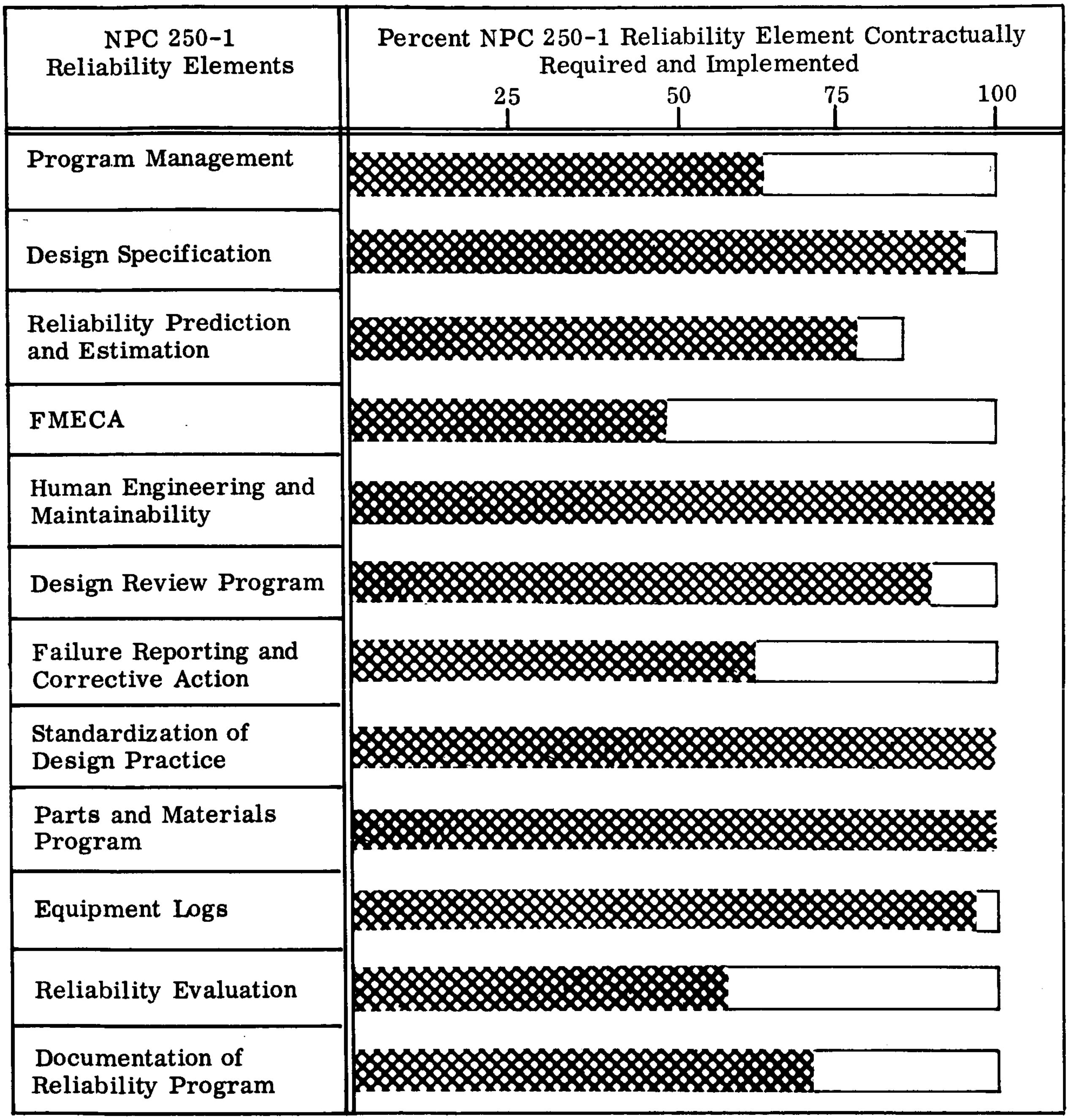


KEY:

Scheduled: Software ▽ Hardware ○

Completed: Software ▼ Hardware ●

Figure 1-29. S-IU-IB Stage Reliability and Quality Assurance Milestones



Contractor IBM Huntsville

Contract No. NAS8-14000

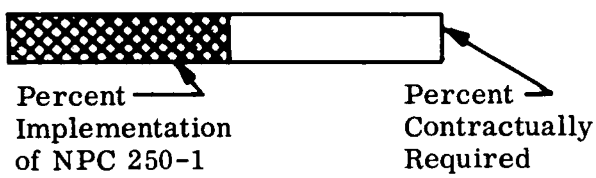


Figure 1-30. S-IU Stage Reliability Assurance Evaluation Based on NPC 250-1

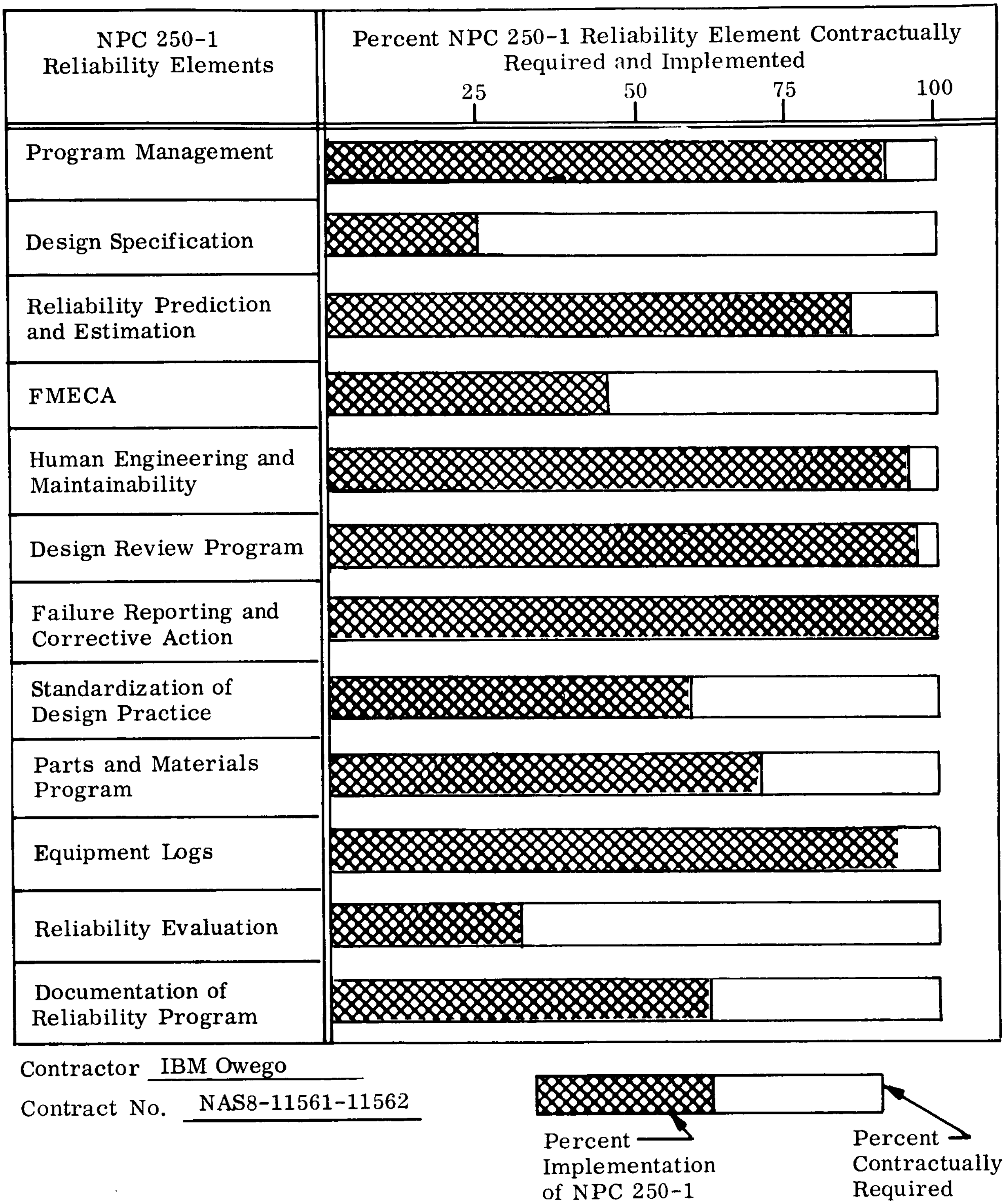


Figure 1-30. S-IU Stage Reliability Assurance Evaluation Based on NPC 250-1 (Cont.)

[redacted]

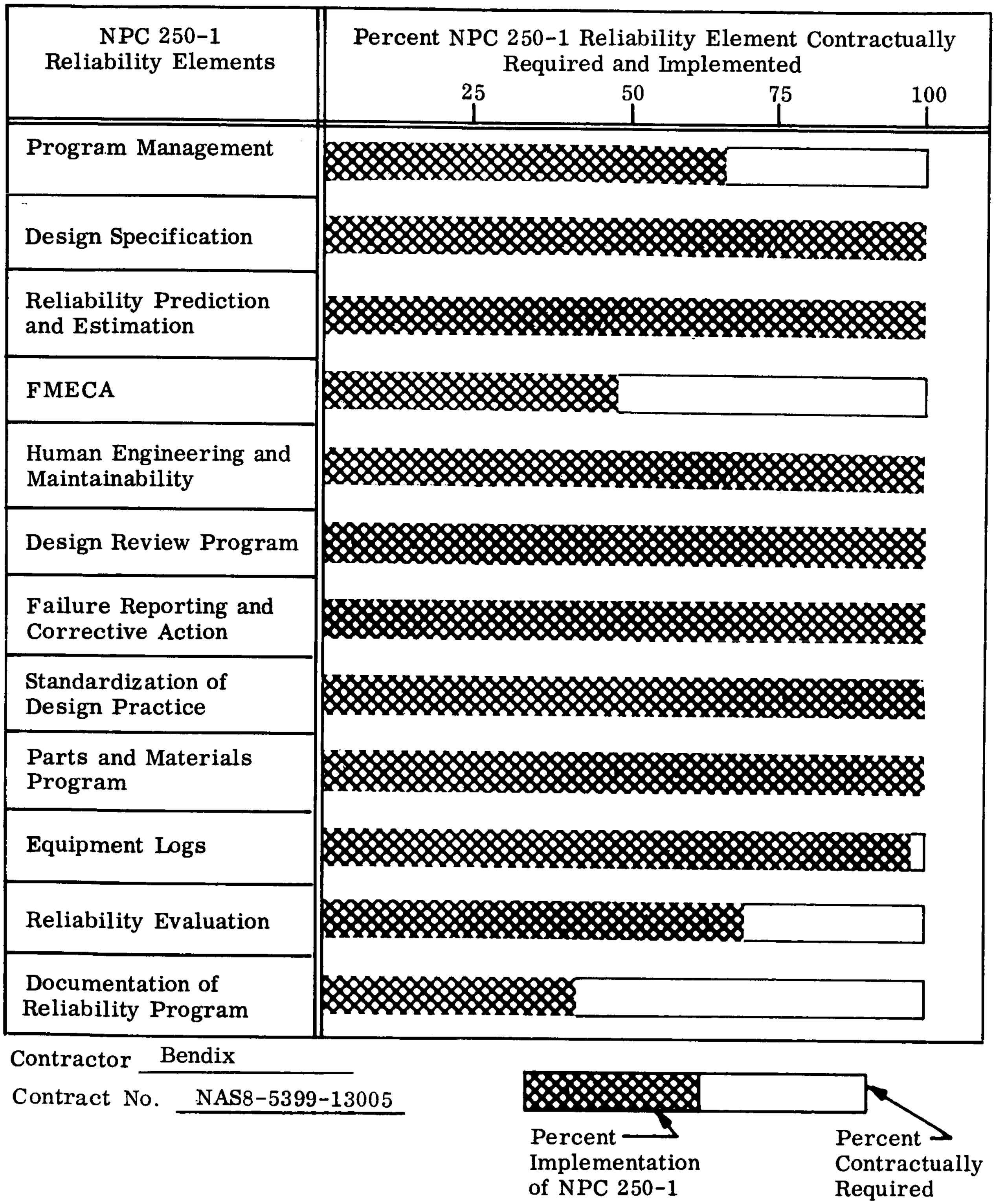


Figure 1-30. S-IU Stage Reliability Assurance Evaluation Based on NPC 250-1 (Cont.)

[redacted]

A major handicap in thoroughly evaluating the degree of contractor compliance with the contract requirements was inadequate documentation. Recommendations for improving the data control and feedback have been transmitted to project management.

1.4.2 RELIABILITY ENGINEERING

1.4.2.1 Design

At the IBM Instrument Unit quarterly review meeting held at MSFC on 12 August 1965, six design modifications were designated as mandatory for S-IU-201. These modifications are as follows:

a. Installation of a flapper valve in the cool air duct, which runs through the umbilical to the IU.

b. Installation of the Environmental Control System (ECS) fluid pump at KSC.

c. Installation of the flight sublimator in the ECS loop at Huntsville to reduce workload at KSC.

d. Installation of a new drain and fill valve in the ECS system.

e. Agreement on cleanliness levels of ECS.

f. Addition of Mylar coating to the pipes from the gas bearing heat exchanger to the stabilized platform.

1.4.2.2 Redundancy and Trade-Off Studies

The planned phase-over to Azusa and ODOP transponders from the MISTRAM and radar altimeter transponders has been accomplished. Therefore, the MISTRAM and radar altimeter systems will be removed from all Apollo-Saturn IB vehicles.

1.4.2.3 FMECA

The final FMECA for S-IU-201 is estimated to be completed by 1 October 1965. The ten most critical items remain the same and are shown in Figure 1-31. This listing is based on the Preliminary Failure Mode, Failure Effect, and Criticality Analysis for S-IU-201 by IBM in May 1965.

Item	Subsystem	Critical Ranking by Flight Stage			
		S-IU 201			
Gyros	Guidance and Navigation	1			
Battery D10	Primary Power	2			
Accelerometer	Guidance and Navigation	3			
Gas Bearing Supply Regulator	Guidance and Navigation	4			
Battery D40	Primary Power	5			
Servo Amplifier	Guidance and Navigation	6			
Memory "A"	Guidance and Navigation	7			
Memory "B"	Guidance and Navigation	8			
Slip Rings	Guidance and Navigation	9			
Pre-Amplifier and Detector	Guidance and Navigation	10			
	REF.	108			

Items Dropped from Preceding List:

Rank	Item

Figure 1-31. S-IU Stage Ten Most Critical Items

1.4.2.4 Mathematical Modeling

Publication of the "Instrument Unit Reliability Model Goal Definition Report" was rescheduled. This report will include a description of the Instrument Unit reliability math model, the goal allocation optimizing scheme, the definition of mission profile, and the goal effectivity schedule.

1.4.2.5 Goals and Prediction

The reliability trend, Figure 1-32, is included in this report to portray the over-all prediction trend against the goal. As additional prediction data is made available by MSFC, an analysis of the reliability improvement increments will be included.

1.4.3 TEST PROGRAM

1.4.3.1 Ground Support Test

A study program is underway at MSFC to evaluate the access door closing anomaly on the S-IU-200/500S structure test vehicle. Changes resulting from this study will be incorporated into S-IU-201. No schedule problem is anticipated at this time.

1.4.3.2 Qualification Test

A summary of total component qualification testing is shown on Figure 1-33. The current over-all test program is slightly behind schedule. No problems are foreseen for completion of critical component qualification in support of the early Saturn IB Flights.

1.4.4 QUALITY ASSURANCE

IBM has reported that some memory plane wires broke during vibration testing. Although the problem was solved, the memory build schedule was disrupted. IBM will reallocate memory modules for various LVDC's to minimize schedule slippage.

Since IBM began building LVDA connector plate assemblies (P/N 6113650), the welds at the end of the ZE10 alloy RF filter have been a source of trouble. Studies showed the welded filter plates to be in tension; whereas, they should have been stress-free or in compression. IBM is now concentrating on improving welding techniques by

[redacted]

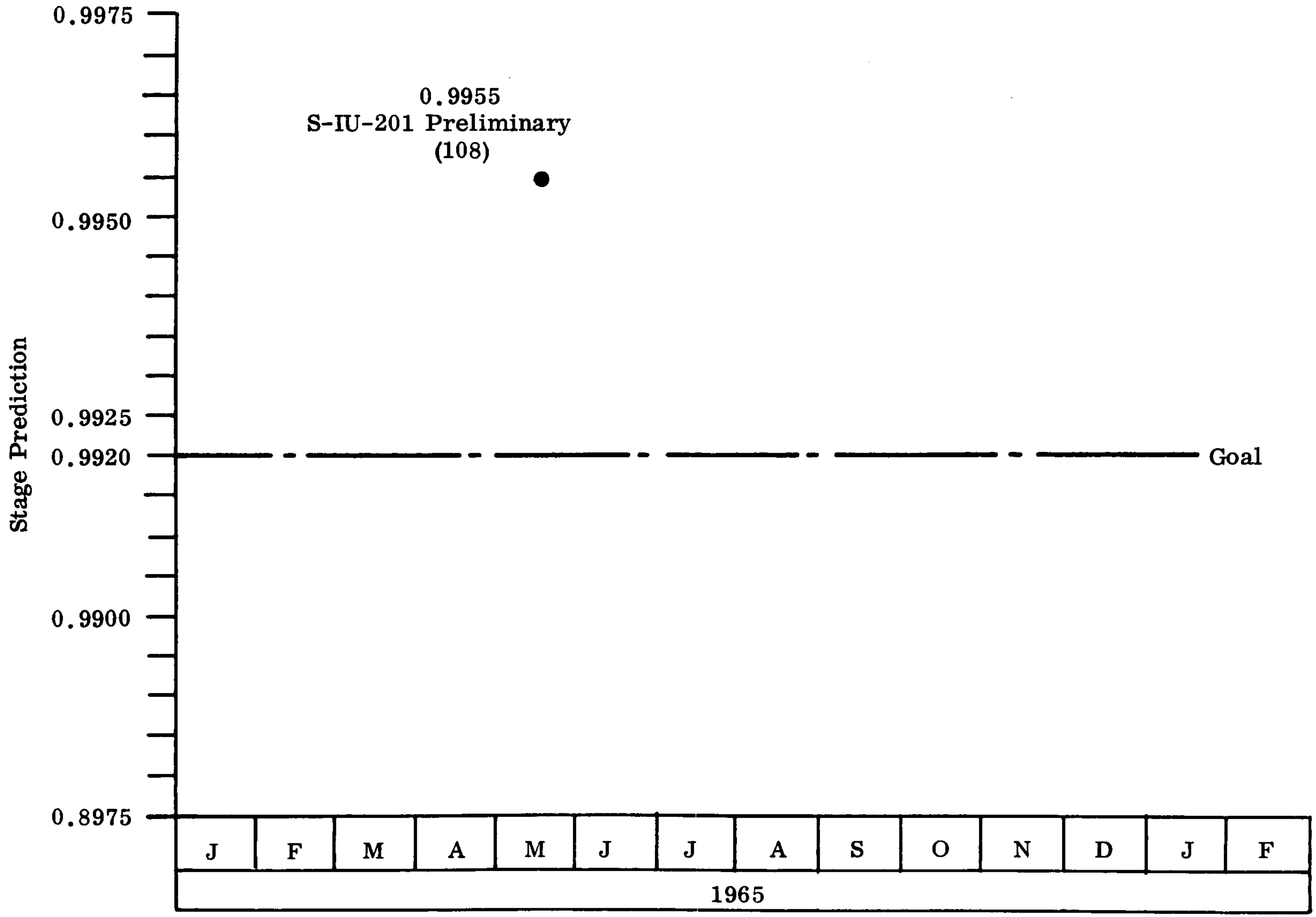


Figure 1-32. S-IU Stage Reliability Trend (Mission Success)

[redacted]

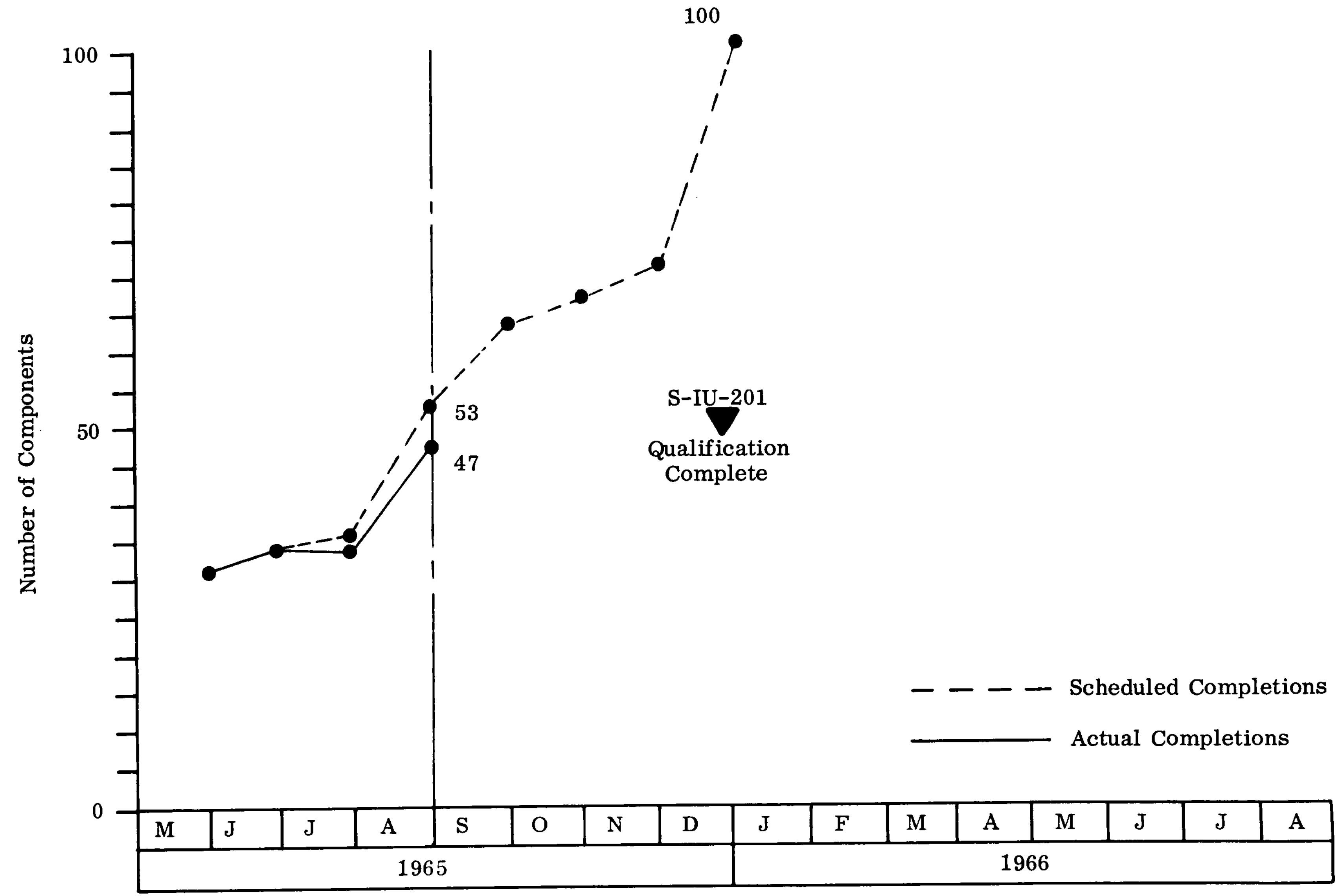


Figure 1-33. S-IU-201 Total Component Qualification

studying weld wire composition and operator methods. This investigation was scheduled for completion by 30 July.

Hard copper has been forming during the copper plating of MIB conductor layers. Although corrective action was taken during the previous quarter, this formation continues to be a problem. IBM Manufacturing Engineering is studying operating parameters to determine possible other causes of this condition.

Unexpectedly high yield losses were occurring at the visual clip and chip inspection station. The problems are equally distributed between chips and clips, the latter resulting from the Level VI redesign. The chip failures (mainly tilted units) are not related to the redesign activities. IBM has instituted procedures to reduce the rejection rates.

1.5 COMMAND SERVICE MODULE

1.5.1 GENERAL

1.5.1.1 Milestones

Two significant milestones were accomplished during this quarter; the flights of Pad Abort-2 and SA-10. Even though the CSM's were of boilerplate configuration, hardware maturity has been enhanced which will improve the reliability of the succeeding flights.

On 29 June 1965, BP-23A (Pad Abort-2) was successfully launched from WSMR. The objective of this flight was to simulate a pad abort from a Saturn I launch vehicle in the event of an emergency. This test utilized a Little Joe II Launch Vehicle and, since all planned test objectives were met, demonstrated the capability to abort from the launch pad and safely recover the Command Module. This test completes the pad abort test program.

BP-9 (SA-10) was successfully launched from KSC on 30 July 1965. This flight was the third Pegasus meteoroid detection satellite and marked the completion of the Saturn I test program. One of the objectives demonstrated by this flight was the successful separation of the boilerplate CSM from the S-IV stage.

Additional milestones include the following:

a. Completion of FMEA for SC-012 (Apollo-Saturn 204 Mission).

b. Issuance of the "Preliminary Apollo Reliability Modeling" document.

A schedule of the reliability milestones for SC-009 (SA-201), SC-011 (SA-202), and SC-012 (SA-204) is presented in Figure 1-34.

1.5.1.2 Reliability Program

The document entitled Apollo Reliability Program Plan, SID-62-203, has been updated by NAA/S&ID, and a proof copy dated 15 August 1965 was made available for NASA review.

NAA is currently investigating the use of PERT as a reliability management tool. PERT is being applied to SC-012 reliability milestones and activities for a one-month trial period to test the effectiveness of this technique.

The action taken on the problems reported in the second quarter status report is presented in the following:

a. The development and qualification of dual-mode explosive bolt for LES tower separation has been unsuccessful to date. The current plan is to use a single-mode bolt on SC-002 and SC-009 and to investigate other techniques to satisfy the redundancy requirements for tower separation on subsequent vehicles.

b. A new pneumatic valve actuating system for the bipropellant valves on the Service Propulsion Subsystem has replaced the hydraulically activated system. This is expected to resolve the problem of erratic opening and closing times.

c. A new reefing line cutter is being developed that is expected to resolve the problem of failure at low temperatures.

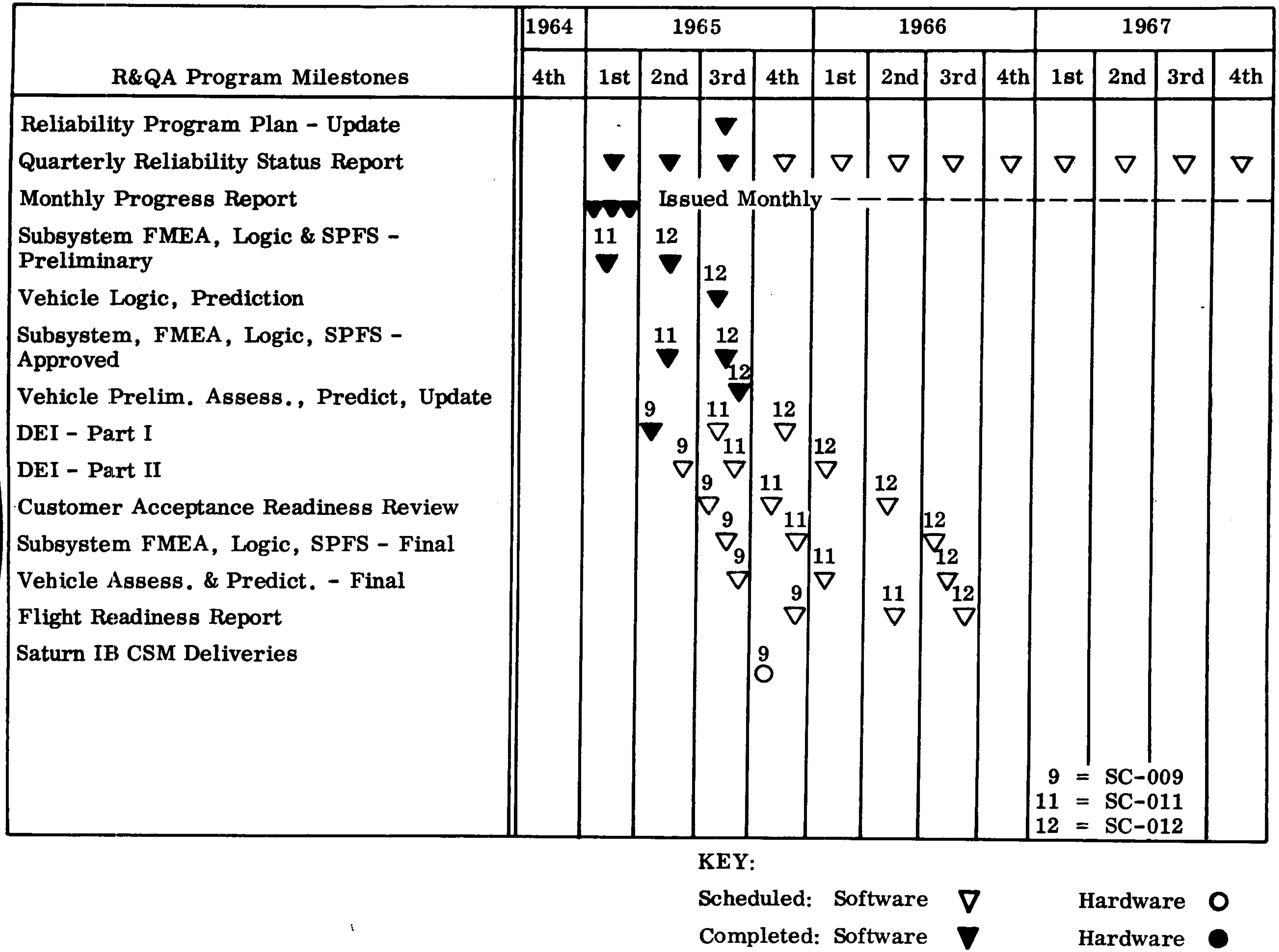


Figure 1-34. Command Service Module Reliability Milestones

d. Ground tests on SC-004 and SC-007 are still behind schedule, but this slippage is not expected to affect the launch schedule for SC-009.

e. The problem of adhesive bonding on CM structures has not been resolved. Possible solutions include a different technique for the application of the adhesive or the use of a different type of bonding process.

f. Design review approval for the Command Module Reaction Control Subsystem is still pending.

1.5.2 RELIABILITY ENGINEERING

1.5.2.1 Design

Design reviews have been completed on the following subsystems:

- CM-SM Reaction Control
- CM-SM Structures
- Service Propulsion
- Sequencers
- Communications
- Stabilization and Control
- Launch Escape
- Instrumentation
- Guidance and Navigation
- Data

1.5.2.2 Redundancy and Trade-off Studies

NAA has a continuing program of redundancy and trade-off studies, but information is lacking to evaluate the extent and effectiveness of this program.

1.5.2.3 FMECA

The SC-012 FMEA has been completed by NAA/S&ID and consists of 19 volumes. This will serve as the basic FMEA for other Block I spacecraft.

The preliminary FMEA for all CSM subsystems on SC-011 was completed in May 1965 and the final FMEA is scheduled for completion by the end of this year. The final FMEA for SC-009 was scheduled for completion by 1 September but is still incomplete.

1.5.2.4 Mathematical Model

The Preliminary Apollo Reliability Modeling document was issued by NAA/S&ID to NASA in May 1965. The document contains a description of the current mission analysis computer program, consisting of the subsystem conditional reliability model and the integrated system reliability model. The mathematical models and their computer programs are utilized in performing system reliability predictions and apportionments.

NAA performed a preliminary mission success functional assessment for SC-009 and obtained an indicated reliability of 0.989.[123] The final assessment is scheduled to be completed 15 November 1965. The functional assessment studies assumed the following:

a. All planned tests were successfully completed.
b. No unsolved problems remained, i.e., zero failures.
c. The functional reliability at 60 percent confidence for individual functions was maintained constant.
d. Logic diagrams were combined in accordance with indicated redundancy.

1.5.2.5 Apportionment and Prediction

The Block I apportionments and predictions, originally scheduled for 18 June, are now 30 percent complete and are scheduled to be finished by 22 November 1965.

The preliminary predictions for SC-012 are scheduled for completion by 29 October 1965.

A tentative schedule (as of 10 August 1965) of Reliability Predictions for SC-009, SC-011, and SC-012 is presented in Figure 1-35.

1.5.3 TEST PROGRAM

The concept of constraint tests and component qualification tests has been replaced by the Certification Test Network. This network represents a compilation by NAA/S&ID of all spacecraft hardware testing (component, development, qualification, design verification, mission simulation, system tests, flight tests, etc.) required to support a specific flight spacecraft.

1.5.3.1 Ground Support Tests

The supporting ground test program for SC-009 and SC-011 is presented in Figure 1-7. This chart identifies all the supporting ground tests; whereas, in the second quarter status report, only the constraint tests for SC-009 were indicated.

The test of SC-002 is a very important supporting test for SC-009, since it will be the first spacecraft configured CSM to undergo a flight test. This is significant because of the results of the acoustic tests on the SC-007 Service Module. These tests revealed areas of weakness in the structural integrity of the flight type spacecraft when exposed to the noise pattern and levels predicted for launch and transonic flight. The flight of SC-002 is scheduled for October 1965; if it is successful, no problems will arise. However, if some of the major test objectives are not satisfied and it becomes necessary to utilize the back-up test vehicle (SC-010), scheduling problems may result. Present flight dates are January 1966 for SC-009 and August 1966 for SC-010. This scheduling of SC-010 does not appear too realistic in utilizing it as a back-up test vehicle for SC-002.

The acoustic tests on SM-007 were completed on 25 June 1965, but as a result of structural failures, additional tests were performed on the Service Module from SC-006. These additional tests, which were completed on 13 August, were conducted

[redacted]

Tasks	S/C 009	S/C 011	S/C 012
1. Mission Objectives and Sequence of Events	-	-	-
2. Operating Time Lines (Mission and Aborts)	-	-	-
3. Subcontractor Reliability Prediction and Failure Rates	-	-	-
4. Vehicle/Subsystem Schematics and "As Design" Configuration	-	-	-
5. Computer Logic Diagram Generic and Failure Rate File	-	-	-
6. Mission Reliability Model (Analytical)	-	-	-
7. Mission Reliability Model (Computer)	-	-	-
8. Preliminary Prediction and Vehicle Goal	-	-	-
9. Preliminary Reliability Prediction Workbook	-	-	-
10. Preliminary Reliability Data Verification	-	-	8/10/65
11. Update Data (1 through 5)	-	-	8/13/65
12. Update Mission Model	-	-	8/23/65
13. Update Reliability Prediction	-	-	9/1/65
14. Update Reliability Prediction Workbook	-	-	11/15/65
15. DEI Data Verification (Delta from 10)	-	-	12/1/65
16. Final Reliability Data Verification	9/10/65	1/21/66	6/11/66
17. Final Reliability Prediction	9/21/65	2/21/66	7/1/66
18. Final Reliability Prediction Workbook	10/1/65	3/1/66	7/1/66
19. Pre-FRR Reliability Data Verification	10/7/65	3/7/66	7/7/66

Figure 1-35. NAA Tentative Block I CSM Flight Vehicle Reliability Prediction Schedule

[redacted]

at reduced noise levels with inconclusive results. The remaining acoustic tests are scheduled to start 1 October on CM-007. Since these tests will be conducted at the increased noise level, the results should provide information necessary to determine the structural integrity of the spacecraft.

There appears to be an abundance of ground test vehicles demonstrating Command Module water impact, flotation, and recovery. The following vehicles have similar test objectives:

a. BP-25, a Command Module for water recovery and handling equipment. The test has been completed.
b. BP-28, a Command Module for land and water impact tests.
c. BP-2, a Command Module for uprighting and flotation tests.
d. BP-29, a Command Module for static stability, uprighting, and flotation tests.
e. BP-12A, a refurbished BP-12 Command Module for water impact tests.
f. SC-007, a Command Module for water impact tests.

1.5.3.2 Certification Tests

The certification tests in this report replace the component qualification status portion of the second quarter status report. Although the Certification Test Network encompasses all phases of hardware testing, the major portion of it consists of the component qualification test program. The status of the certification test program for SC 009 and SC-011 is presented in Figure 1-8. This figure indicates 94 certification tests behind schedule for SC-009 and 95 tests behind for SC-011 as of 1 July 1965, and it represents a slippage of 41 percent on SC-009 and 43 percent on SC-011 of planned test completions.

The majority of the SC-009 slippage can be attributed to the following subsystems:

a. Service Propulsion.
b. Electrical Power.
c. Structures.
d. Ordnance.
e. Stabilization and Control.

The following subsystems have experienced problems during testing that could prevent the completion of their formal test program by the presently scheduled SC-009 launch date:

a. Reaction Control Subsystem - The CM and SM nitrogen tetroxide tanks have failed when tested with the oxidizer under temperature and pressure. The existing tanks can be used on SC-009 and SC-011 under restricted usage limits; however, they would not be acceptable for SC-012.

b. Ordnance Devices - Various cartridges have failed certification tests. The present design is adequate for SC-009 and SC-011 but will not meet the requirements of manned flight. Recommended corrections to the problem are under consideration.

c. Service Propulsion - The gimbal actuator clutches are demonstrating greatly reduced service life.

   A redesign would result in a long delay; however, it is possible to operate the clutches at reduced speed prolonging the life. The problem is still under consideration.

1.5.4 QUALITY ASSURANCE

1.5.4.1 Quality Milestones

Figure 1-36 shows the status of the spacecraft quality program in terms of scheduled and completed milestones. These milestones pertain to activities associated with the prime contractors.

1.5.4.2 Quality Problems

There has been a significant recurrence of potting separation on modules on the power and servo assembly of the Apollo G&N system. The failure mode itself is minor; however, two critical failures have occurred when moisture penetrated the separation and internally shorted two modules. Also, more than one occurrence is frequently noted on a single failure report. Approximately 200 modules and 30 trays are involved. Several corrective action methods have been taken, but as of latest reporting, satisfactory solutions to the problem have not been demonstrated.

1965

Documents	J	F	M	A	M	J	J	A	S	O	N	D
Quality Program Plans												
NAA											▽1	
ACED									▽			
GAEC											▽1	
GA/NAA					▼1							
GA/ACED									▽			
GA/GAEC											▽1	
Quality Status Reports												
NAA (Monthly)					▼2							
GAEC (Monthly)						▼2						
GA/NAA (Monthly)					▼2							
GA/GAEC (Monthly)						▼2						
GA/ACED (Monthly)							▼2					
ACED (Quarterly)						▼2						
Quality Program Reviews												
NAA (Monthly)									▼3			
ACED (Monthly)								▼2	▽3			
GAEC (Monthly)									▼			

▽ - Scheduled
▼ - Actual
▽1- Update
▽2- Latest Report Received
▽3- Initial Review Scheduled

Figure 1-36. Spacecraft Quality Program Milestones

At present CSM 009 has 626 applications of non-Apollo qualified parts of which five are connector applications that affect primary mission objectives. MSC is reviewing a list of non-high-reliability hardware intended for use on CSM 009 to determine corrective action requirements. Special tests are being conducted to verify the integrity of CSM 009 application of commercial plugs in humidity and salt spray environments. One particular problem concerning the use of non-Apollo qualified parts on CSM 009 has already been evidenced; viz, the Master Events Sequencer Controller which has consistently failed.

Two fuel cells failed qualification testing. The first failed after 101.75 hours of the vacuum endurance test and was subjected to a complete teardown analysis by Pratt & Whitney. The cause of failure was established to be contamination introduced by the cleaning fluid used in preparing the equipment for oxygen service, which resulted in plugging of the oxygen lines. To prevent recurrence, Pratt & Whitney has instituted more elaborate gas sampling procedures prior to each test, more rigid purges after any rework, and review of all assembly and test procedures. The second qualification fuel cell experienced an internal short circuit 16 hours prior to the end of the 400-hour qualification program. The primary cause of the failure was established as dendritic shorting. The second fuel cell met the present Block I Apollo mission specification requirements. No design changes are anticipated as a result of this failure.

MSC Engineering and Development requested assistance in evaluating the adequacy of the Quality Assurance program requirements of the Sperry Rand Corporation Contract NASw-2847, for the Apollo Series 16 Pulsed Integrated Pendulum. A complete review of the contractual requirements and Sperry's compliance thereto was, therefore, initiated by MSC Reliability and Quality Assurance. Several potential problem areas exist, some of which have been corrected, with the balance to be resolved within the next quarter.

1.5.4.3 Quality Trends

Figure 1-37 represents the number of contract and engineering waivers per month on the Apollo G&N Systems. GA/ACED reports indicate that no waivers have been granted which would affect quality, reliability or performance. As of 10 June 1965, G&N System number 12 was received at NAA, joining systems 8, 20, and 17 already at NAA.

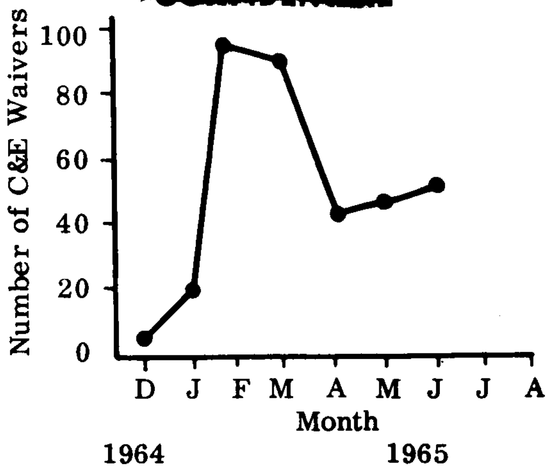


Figure 1-37. Contract and Engineering Waivers Granted per Month on Apollo G&N System

Figure 1-38 represents the number of failures as of 1 July 1965 on the individual G&N Systems.

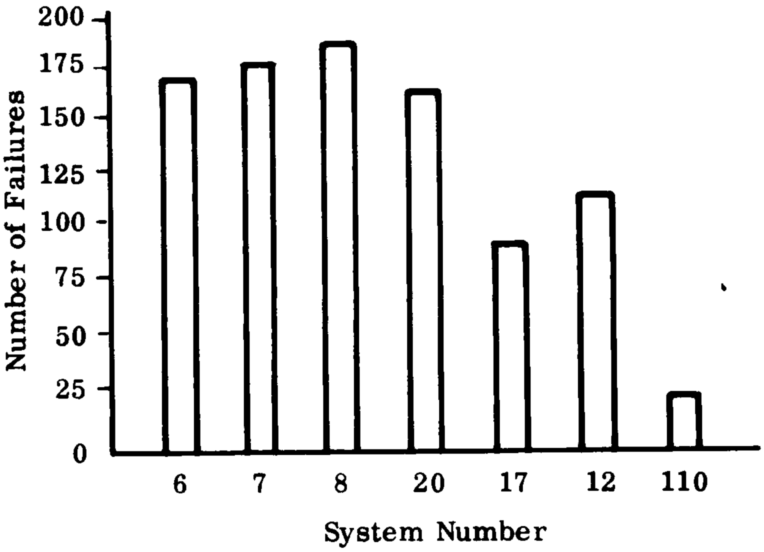


Figure 1-38. ACED G&N Failures by System as of 7/1/65

Figures 1-39 and 1-40 indicate the trends in quality performance of the prime contractors during the manufacturing cycles. The measurement on the CSM is Material Review Board actions per thousand manufacturing hours and the measurement on the Apollo G&N is defects per thousand manufacturing hours.

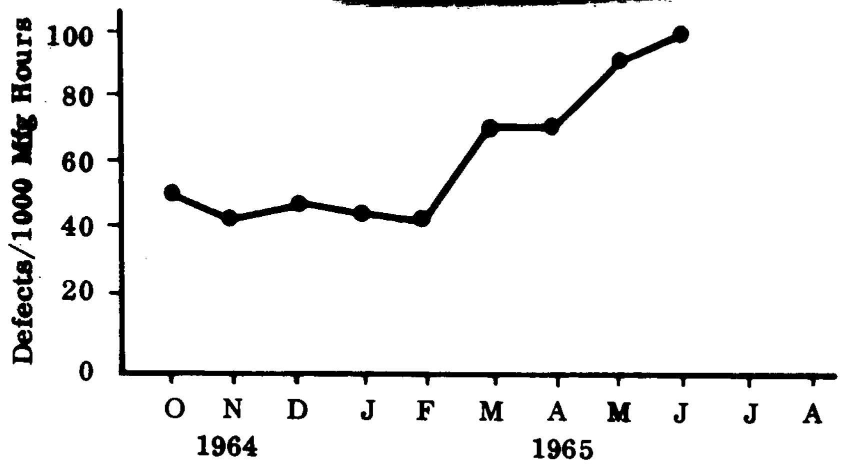


Figure 1-39. ACED G&N Defects/1000 Manufacturing Hours

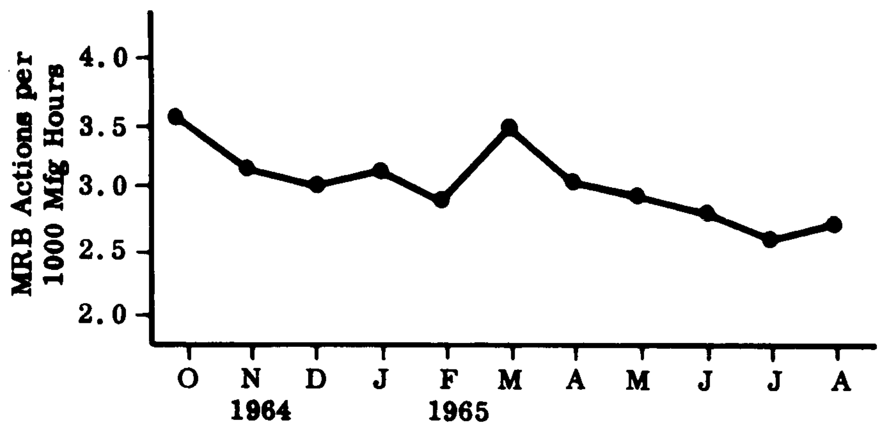


Figure 1-40. NAA CSM Material Review Actions per 1000 Manufacturing Hours

1.6 LAUNCH COMPLEX AND GSE

1.6.1 GENERAL

Appolo-Saturn IB vehicles will be launched from Launch Complexes 34 and 37B at KSC. Modifications and additions to each of these facilities were necessary in order to accommodate the Apollo-Saturn IB vehicles and to provide systems for manned spacecraft operations. Detailed descriptions of the Launch Complex 34 modifications are found in the KSC "Launch Complex 34 Modification Plan" prepared by KSC; the "Launch Complex 37B Modification Plan" is being prepared for issue in the last quarter of 1965.

Many modifications to Launch Complex 34 have been completed, and the facility checkout has begun in accordance with the "Launch Complex 34 Facilities Checkout Plan" prepared by KSC. Delays of more than one week have been incurred in the demonstration of cryogenic facility capabilities. Validation of electrical control and monitor networks with Ground Equipment Test Sets (GETS) is also being conducted, and schedule delays of ten days to two weeks have been incurred. These delays are attributed to computer and network troubles.

Failure Mode Effect and Criticality Analyses of launch complex equipment are planned for each Apollo-Saturn IB mission. These analyses for the Apollo-Saturn 201 Mission analysis have been completed and presented to the Crew Safety Panel on 21 and 22 September. Redesign of the Holddown Arms to improve reliability has been undertaken.

Two ACE-S/C stations have been delivered and are operating at KSC. The second station was accepted on 8 August, ahead of schedule. The activation of this station eliminates a major problem area in developing ACE-S/C programs for CSM-009 checkout at KSC.

Apportionment and prediction studies on ACE-S/C were essentially completed, and emphasis has shifted to assessment and improvement of systems through failure analysis. As part of the evaluation program, General Electric/ASD is evaluating a representative station in the spacecraft checkout mission at KSC. While still below the mission reliability goal of 0.998, the trend of system reliability is upward. (See Figure 1-41).

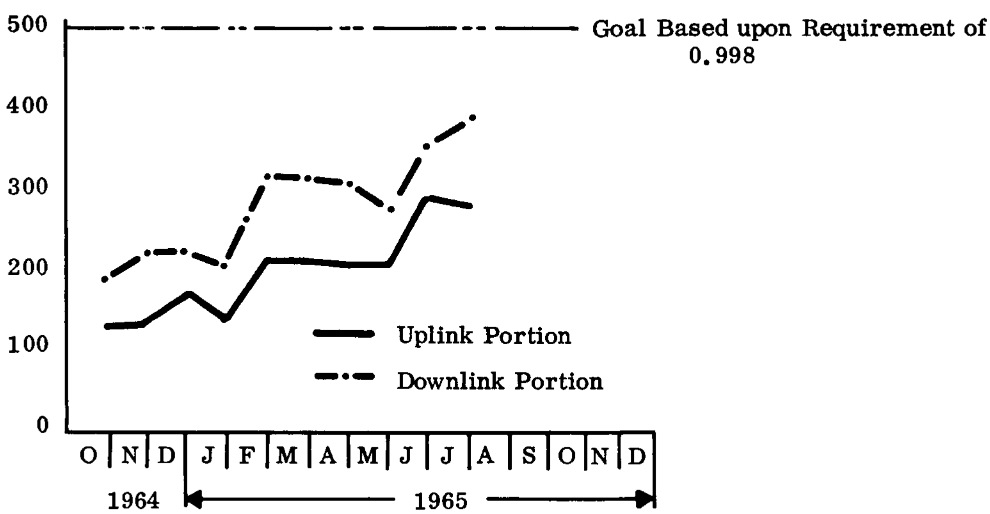


Figure 1-41. ACE-S/C MILA Mission Evaluation T-1 to T-0 Trend Chart

No over-all analysis of the launch operation aimed at analyzing and assuring capability to meet mission launch windows has been undertaken.

1.6.2 LAUNCH COMPLEX RELIABILITY ENGINEERING

1.6.2.1 Launch Complex 34

Preliminary Failure Mode and Effect Analyses and the Criticality Analyses for most Launch Complex 34 systems for the Apollo-Saturn 201 Mission have been completed. These analyses identify those launch complex systems in which failures could cause loss of the vehicle or create hazardous conditions for launch operations crews or astronauts and criticality numbers are calculated. Fourteen systems include 89 items which could have this failure effect. These systems are listed in Figure 1-42. Also listed in Figure 1-42 are other launch complex systems in which malfunctions would result in failure to detect or report a vehicle failure, thus permitting hazardous conditions to continue endangering vehicle or personnel. No criticality numbers are shown because some systems are being reworked. Redundancies are being included in the Holddown Arms, for example, to reduce the over-all criticality.

Vehicle Loss	Safety Problem
Environmental Control	Lightning Warning
Liquid Hydrogen	Hydrogen Detection
Liquid Oxygen	Hypergolic Propellant Detection
Pneumatic Facility	Combustion Stability Monitor
RP-1 Fuel	Fire Detection Monitor
Holddown Arms	Hazard Proofing
Fuel Fill and Drain Mast	Firex
LOX Replenish Mast	Power
Pneumatic Distribution	Boat tail Condition and Water Quench
Swing Arm No. 1	
Swing Arm No. 2	
Swing Arm No. 3	
Swing Arm No. 4	
LOX Fill and Drain Mast	

Figure 1-42. Saturn IB, LC-34 Failure Mode and Effect Analysis Summary

1.6.2.2 Launch Complex 37B

In general, the equipment to be installed in Launch Complex 37B is similar to that being prepared for Launch Complex 34, and it is scheduled for delivery after similar equipment is installed at Launch Complex 34. Schedules for delivery of Launch Complex 37B equipment are extremely tight (especially for ESE equipment). This will create a need for greater R&QA effort to assure that standards are not relaxed as a result of increasing pressure to meet schedules. Failure Mode and Effect Analyses and Criticality Analyses are planned for each mission launched from this complex, but no results are available at this time.

1.6.2.3 GSE Acceptance Procedures for Launch Complex 37B

Major GSE and Facilities equipment will be accepted by KSC after demonstration testing has been satisfactorily accomplished. KSC has no plans or procedures for performing acceptance tests or inspections at KSC on equipment procured by contractors and that procured by KSC and other Centers. This equipment, which includes racks, cabinets, cables, etc., would normally be checked out at their source and will not be rechecked at KSC.

1.6.3 ACE-S/C RELIABILITY ENGINEERING

The over-all Failure Mode Effect Analysis work is being performed by General Electric/ASD. Inputs from Control Data Corporation and Radiation, Incorporated are being integrated by General Electric. The basic FMEA task is completed; the over-all FMEA report is expected to be published by October 1965. These FMEA's include a Criticality Classification for effect of the failure mode on ACE-S/C Ground Station.

A failure reporting and corrective action system has been operated by General Electric/ASD throughout the program. Other suppliers of ACE-S/C equipment have not had requirements for failure analysis; therefore, the failure analysis program has been incomplete. NASA/MSC has taken action to correct this problem by assigning over-all failure analysis responsibility to General Electric/ASD with support from Control Data Corporation and Radiation, Incorporated.

General Electric/ASD is performing monthly evaluations of the reliability of a representative ACE-S/C ground station at KSC for the Apollo Spacecraft checkout mission. The results of all mission evaluations through 1 July 1965 are plotted on the ACE-S/C MILA Mission Evaluation Trend Chart (Figure 1-41). This chart has been developed from failure reports categorized as "mission critical"; these are failures that might result in scrubs or holds. Actual MTBF's are presently improving as the number of infant mortalities are decreasing; the experience of station operating personnel is increasing; and design debugging continues. To date, only the last hour (T-1 to T-0) of the launch operation has been evaluated.

Information from operating ACE-S/C stations is continuously monitored. The MTBF trends of systems and subsystems are continuously monitored and investigations are initiated in those areas where potential problems are indicated. System availability, as represented by mean hold time, is also used as a measure of ACE-S/C performance. The trend of mean hold times is shown in Figure 1-43. The same factors affect this measure as affect the MILA mission evaluation.

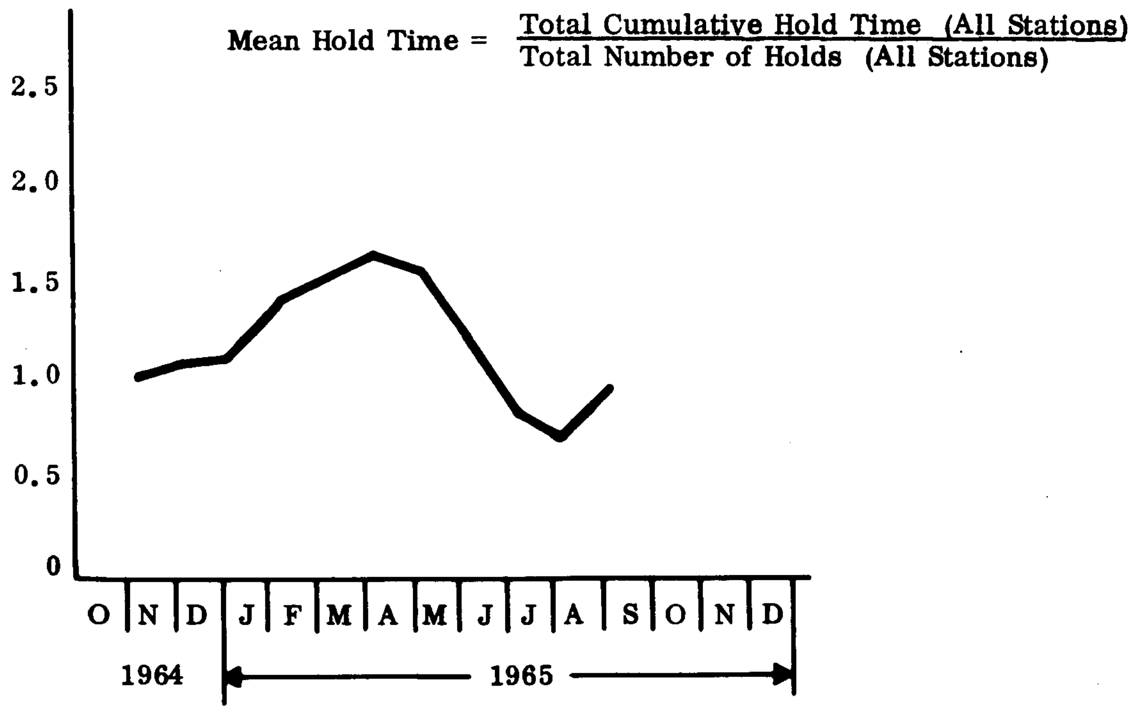


Figure 1-43. ACE-S/C Availability

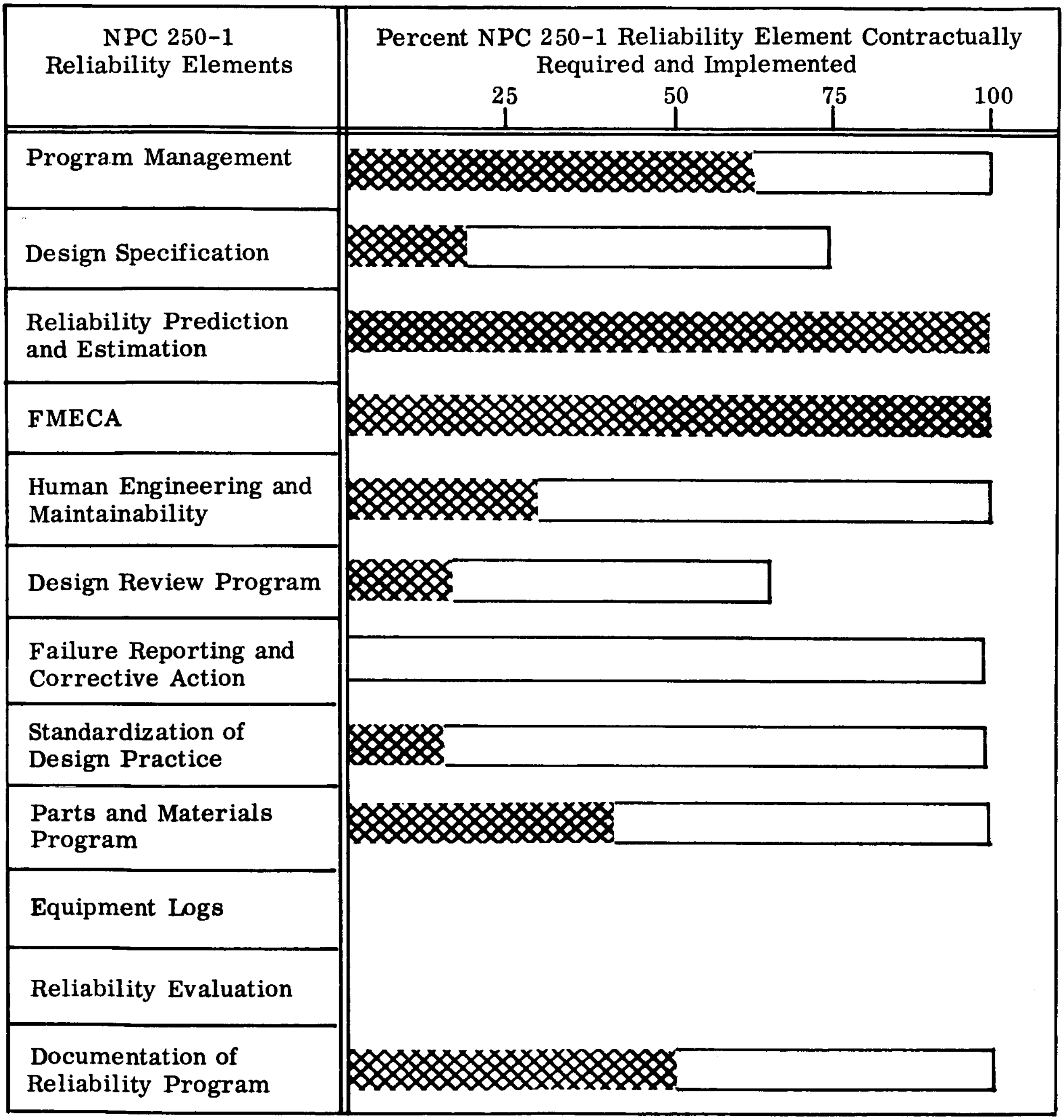
1.6.4 ELECTRICAL SUPPORT EQUIPMENT RELIABILITY ENGINEERING

Failure Mode and Effect and Criticality Analyses are being performed for Saturn IB Electrical Support Equipment (ESE) by General Electric/ASD in Huntsville. Since ESE equipment plays an important part in the over-all mission success, vehicle loss could result from an independent ESE failure or from an ESE malfunction which results in failure to detect and report a vehicle failure. Also, should the ESE falsely report a malfunction when no malfunction occurs, an unwarranted hold or scrub condition could result. It is sometimes possible for Operation Crews to override malfunctions of ESE equipment for continuance of countdown.

Reliability program status of the ESE contracts is shown in Figure 1-44. Progress in each of the program elements since the last reporting period is depicted by cross-hatching. It should be noted that certain of the NPC 250-1 program elements do not apply at this stage of the program and thus are not being 100 percent contractually implemented.

In Figure 1-45, functions are shown which have been determined to include one or more items which could have the failure effect shown. No independent ESE IU Stage hardware failures were located that could result in vehicle or mission loss. However, a failure in one particular circuit (initiates closure of theodolite hut window shutter when ignition command is issued) could cause blast damage to the theodolite. Similarly, no independent ESE System Integration hardware failures could result in vehicle or mission loss. However, there are three components whose failure could also cause possible blast damage to the theodolite.

Numerical reliabilities have been computed for the total ESE equipment furnished by all suppliers. Over-all results for the three major groups; Launch Vehicle, Automatic Ground Control System (AGCS), and Launch Control Center (LCC) are summarized in Figure 1-46 (Reference 96).



Contractor General Electric Company

Contract No. NASw-410

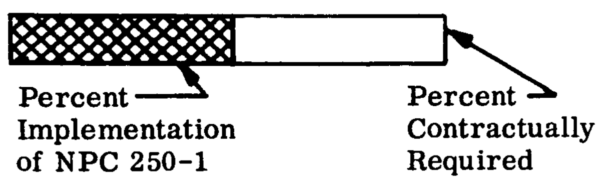


Figure 1-44. Electrical Support Equipment Reliability Assurance Evaluation Based on NPC 250-1

Function or Subsystem	Vehicle Loss Could be Caused by: An Independent ESE Failure	Vehicle Loss Could be Caused by: Both an ESE Failure and Vehicle Failure	Corrective Manual Override of ESE Possible
S-IB Stage ESE			
Launch Sequencer	X		X
Control Spheres		X	
Fuel Pressurization		X	
LOX Pressurization		X	
Cutoff Command		X	X
Purges	X	X	X
Commit	X		
S-IVB Stage ESE			
Hydraulic Systems Ready		X	X
LOX System		X	
LH_2 System		X	
S-IV Ready for Launch		X	
IU Stage ESE			
Power		X	X
Cooling GN_2			
Pneumatics		X	X
Switch Selector		X	X
Flight Control System		X	X
Measuring and Tracking		X	X
ST 124 Platform System		X	X
EDS/Control Rate Gyro		X	X
IU Ready for Launch		X	X
Liftoff, Ignition, Commit			
Systems Integration ESE			
Ground Pressures		X	X
Umbilical Control		X	X
Camera Control		X	X
Apollo Access Arm Control		X	X
Vehicle Networks		X	X
Pad Safety		X	X
Test Conductors & Supervisors		X	X
Stage Integration		X	X
Power ESE			
S-IB Power		X	X
S-IV Power		X	X
IU Power		X	X
Auxiliary Power		X	X

Figure 1-45. Saturn IB ESE Criticality Analysis Summary

	Vehicle	AGCS	LCC
Apportioned (7 Hours)	0.9842	0.9920	0.9922
Predicted (7 Hours)	0.7406	0.8571	0.8641

Figure 1-46. Summary Of Saturn IB ESE Total System Reliability

1.6.5 TESTING PROGRAM

1.6.5.1 Launch Complex 34 Facilities Checkout

The Launch Complex facilities checkout is intended to verify the facility functional status and compatibility of ground support equipment and the space vehicle. Details of the checkout are documented in the Launch Complex 34 Facilities Checkout Plan. Figure 1-47 identifies the major operations required to satisfy the checkout objectives. Concurrently with this facility checkout program, a series of Computer-Ground Equipment Test Sets tests are being performed to validate electrical control and monitor networks required for all discrete signal circuits. These tests are reported below in Paragraph 1.6.5.3.

The facility checkout program began in August 1965 with the erection of the S-IB-1 flight stage. The S-IVB-F and IU-F facilities stages were erected in late August. IU-F component handling and ST-124 platform installation were completed. Spacecraft erection and fit checks were expected to be performed in late September with the Spacecraft Facilities Vehicle.

The S-IVB-F manual LOX loading operation was completed on 9 September in preparation for the automatic loading operation. As of mid-September, however, S-IVB-F LOX and fuel loading operations were 9 days behind the schedule necessary to meet the operational required date. Detailed schedule information is not included here, but it is available in the Launch Complex 34 Site Activation room at KSC.

Checkout Objectives	Major Operations: S-IB-1 Stage Erection and Fit Checks	S-IVB-F Stage Erection and Fit Checks	IU-F Erection and Fit Checks	Spacecraft Erection and Fit Checks	S-IB RP-1 Auto Loading	S-IB LOX Auto Loading	S-IVB-F LOX Auto Loading	S-IVB-F LH_2 Auto Loading	S/C Fluids Flow Tests	S-IVB-F APS Propellant Loading	De-mating
Verify Stage and Spacecraft Handling Equipment and Techniques	X	X	X	X							X
Demonstrate S/V-to-Facility Mechanical Compatibility	X	X	X	X	X	X	X	X		X	X
Verify Inert Ordnance Handling Equipment and Techniques		X		X							X
Demonstrate Operational Capability of Launch Vehicle RP-1 and Cryogenic Propellant and Gas Facilities					X	X	X	X			
Demonstrate Operational Capability of S-IVB Hypergolic Facilities										X	
Demonstrate Operational Capability of Spacecraft Fluid Distribution System									X		

Figure 1-47. LC-34 Facility Checkout Objectives

Subsystem acceptance and qualification tests are continuing in addition to the major operations shown in Figure 1-47. Figure 1-48 is a summary of failure reports written on KSC supplied mission essential GSE through August. Importance categories are not available at this time.

Subsystem	Failures Reported Through August
RP-1	5
Water Quench	4
Primary Power	1
ECS	2
LOX	2
Gaseous Nitrogen	3
Hydrogen	3
Telemetry	7
Electrical Network	18
Ground Handling Equipment	3
Pneumatics	6
Launch Mast	1
Umbilical Swing Arm	1

Figure 1-48. Mission Essential GSE Failure Reports on KSC Supplied Hardware

1.6.5.2 ACE-S/C Testing

No requirement exists for reliability demonstration testing of ACE-S/C equipment. Evaluation of equipment in its operating environment is therefore receiving emphasis as reported in Paragraph 1.6.3.

1.6.5.3 Computer - GETS Testing

Ground Equipment Test Sets (GETS) are pieces of equipment which simulate Saturn IB vehicle electrical systems. This equipment is used to validate launch complex electrical control and monitor networks without using a flight vehicle. Signal responses normally obtained from the vehicle are provided by GETS to monitor panels or to the computer. These tests are the first demonstration of the capability of the RCA 110A computer to effectively handle operational systems.

Tests of systems of the S-IB, S-IVB, and IU are in process. Computer and network troubleshooting has been stated as the cause for delays which had accumulated to a total of almost two weeks by 17 September. Details of failures or problems encountered are not available.

SECTION 2: APOLLO-SATURN V MISSIONS

2.1 GENERAL

2.1.1 SUMMARY

The Apollo-Saturn V Reliability Programs are separable into two main groupings, i.e., those associated with common 200/500 vehicles (such as the S-IVB and the CSM) and those which are applicable to the 500 Series only (such as the S-IC). This section of the report discusses only 500 Series missions information. It has been assumed that the reader will examine both Sections 1.0 and 2.0 in those instances wherein overlaps of interest occur.

The following paragraphs briefly explain the organization and content of Section 2.0.

a. Apollo-Saturn 504 Reliability Analysis (paragraph 2.1.2) - This paragraph presents the major results of the mathematical analysis of the Apollo-Saturn 504 Manned Lunar Landing Mission. Additional information amplifying and supplementing the results is included as Appendix C to this report.

b. Apollo-Saturn Reliability Program Status (paragraph 2.1.3) - This paragraph presents the present status of the over-all Center/contractor reliability programs and includes test and weight status information as these affect reliability.

c. Stage/Module Reliability Status (paragraphs 2.2 through 2.8) - Each of the stages and modules is discussed in turn and the present reliability status of the hardware programs is discussed.

2.1.2 APOLLO-SATURN 504 RELIABILITY ANALYSIS

2.1.2.1 Introduction

The current reliability status of the Apollo-Saturn 504 Mission and systems is expressed in terms of system and mission phase impact on the chances of crew safety

[redacted]

and mission success, associated technical problems, documented reliability apportionments, reliability predictions, and crew safety and mission success probability degradation as a function of mission time and phase.

The Design Reference Mission Reliability Profile document (Reference 3 of Appendix C) provides the profile data necessary to satisfy the specific needs of the Apollo-Saturn 504 Mission reliability analysis. Cognizant reliability personnel at NASA Centers and Headquarters have received this profile for review and comment. Bellcomm and Marshall Space Flight Center have submitted useful comments primarily dealing with format. This document, based on the Apollo Mission Planning Task Force Design Reference Mission (Reference 2 of Appendix C) provides a substantial amount of additional mission data required for reliability analysis. The document contains ground rules for abort selection for those intervals of the mission where several types of aborts are feasible. For example, during the time period from Launch Escape System jettison to S-IVB ignition, a suborbital abort will be the primary abort choice. However, during the period from S-IVB ignition to earth orbital insertion an abort-to-orbit will be the primary abort mode. Constraints imposed by landing sites are considered and associated profile data necessary for crew safety and mission success probability estimation are also contained in Reference 3 of Appendix C.

Apollo Program documentation, including documents issued by the Manned Space Flight Center, Marshall Space Flight Center, and their respective contractors, provide further basic information for this analysis. Center/contractor reliability prediction and apportionment data, reliability models, and other engineering information were used to structure the Apollo-Saturn 504 Manned Lunar Landing Mission/system simulation model yielding the Apollo Program Office estimates of the following:

a. Predicted system/equipment reliability.
b. Predicted mission phase reliability.
c. Predicted crew safety probability.
d. Predicted mission success probability.

In addition, the unreliability contributions by equipment, system, stage/module, and mission phase were derived from the mission simulation. Tabulations providing comparisons of the results of contractor documented reliability apportionments and

[redacted]

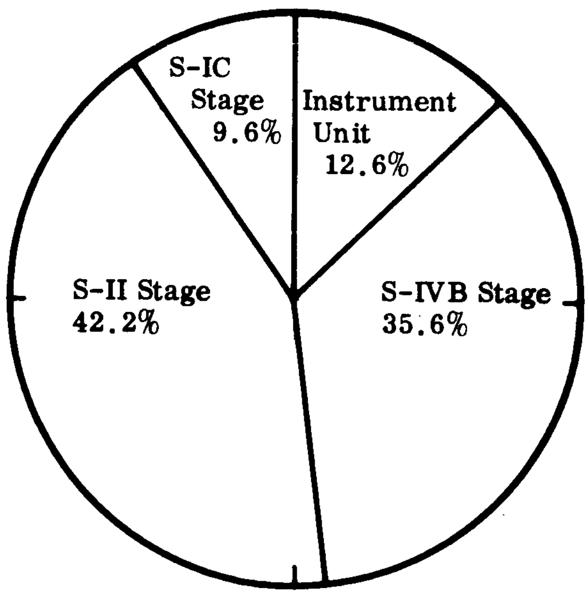
predictions are included in Appendix C. Ground Operational Support System reliability considerations are presented in summarized form. Prelaunch and launch aspects are not included in this analysis.

2.1.2.2 Saturn V Launch Vehicle

The Saturn V Launch Vehicle is composed of the S-IC, S-II, S-IVB, and Instrument Unit. The Saturn V Launch Vehicle reliability prediction value of 0.76 approaches the apportionment of 0.85 stated in the Saturn V Program Development Plan (Reference 10 in Appendix C). There is no significant difference between Apollo Program Office and Center/contractor predictions of mission success for the Saturn V Launch Vehicle.

The S-II and the S-IVB stages are the largest contributors (approximately 42 percent and 35 percent, respectively) to the total Launch Vehicle unreliability of 40 percent. Figure 2-1 shows relative contributions of each Stage to the predicted Launch Vehicle unreliability.

Saturn V Launch Vehicle



Note: 1. The launch vehicle accounts for 40.5 percent of Space Vehicle (Mission) unreliability.
2. Ground operational support system and crew functions were considered to have a reliability of 1.0 for this study.

Figure 2-1. Apollo Saturn 504 Manned Lunar Landing Mission Percentage Contribution of Stages to Launch Vehicle Unreliability

Figure 2-2 shows the predicted Launch Vehicle and Stage success probabilities as a function of mission phase.

The J-2 engines (S-II and S-IVB stages) are the greatest contributors to Launch Vehicle unreliability primarily because of the relatively long operating time of the five engine subsystems during the mission and J-2 malfunction problems. There are other equipments which stand out significantly as main contributors to the Launch Vehicle unreliability. These equipments are the duct gimbal joints and ducting bellows (S-IC Stage), the auxiliary propulsion engines (S-IVB stage), and an equipment selector switch in the S-IVB stage.

The S-IC Stage and the Instrument Unit combined contribute approximately 23 percent to the unreliability of the Launch Vehicle. The stage-by-stage comparison of reliability apportionments and predictions shows no appreciable difference between Center/contractor and Apollo Program Office values.

2.1.2.3 Apollo Spacecraft

2.1.2.3.1 General

The Apollo Spacecraft is comprised of the Command Module, Service Module, and Lunar Excursion Module.

Technological interfaces have given rise to the term "Command Service Module" acknowledging the fact that the two modules function essentially (up to the nominal mission event "Service Module Jettison" at about 198 hours after liftoff) as one unit during the entire mission. Launch Escape System and Adapter considerations are included with those concerning the Command Service and Lunar Excursion Modules, respectively.

Analysis results show that approximately 60 percent of the mission unreliability of the Apollo Space Vehicle is due to the spacecraft. With this percentage taken as a base, the Command Service Module contributes 69 percent and the Lunar Excursion Module contributes 31 percent to Spacecraft unreliability. Of all Spacecraft systems and launch vehicle stages, the Command Service Module Guidance, Navigation, and Control subsystem ranks first with a percentage contribution to predicted over-all mission

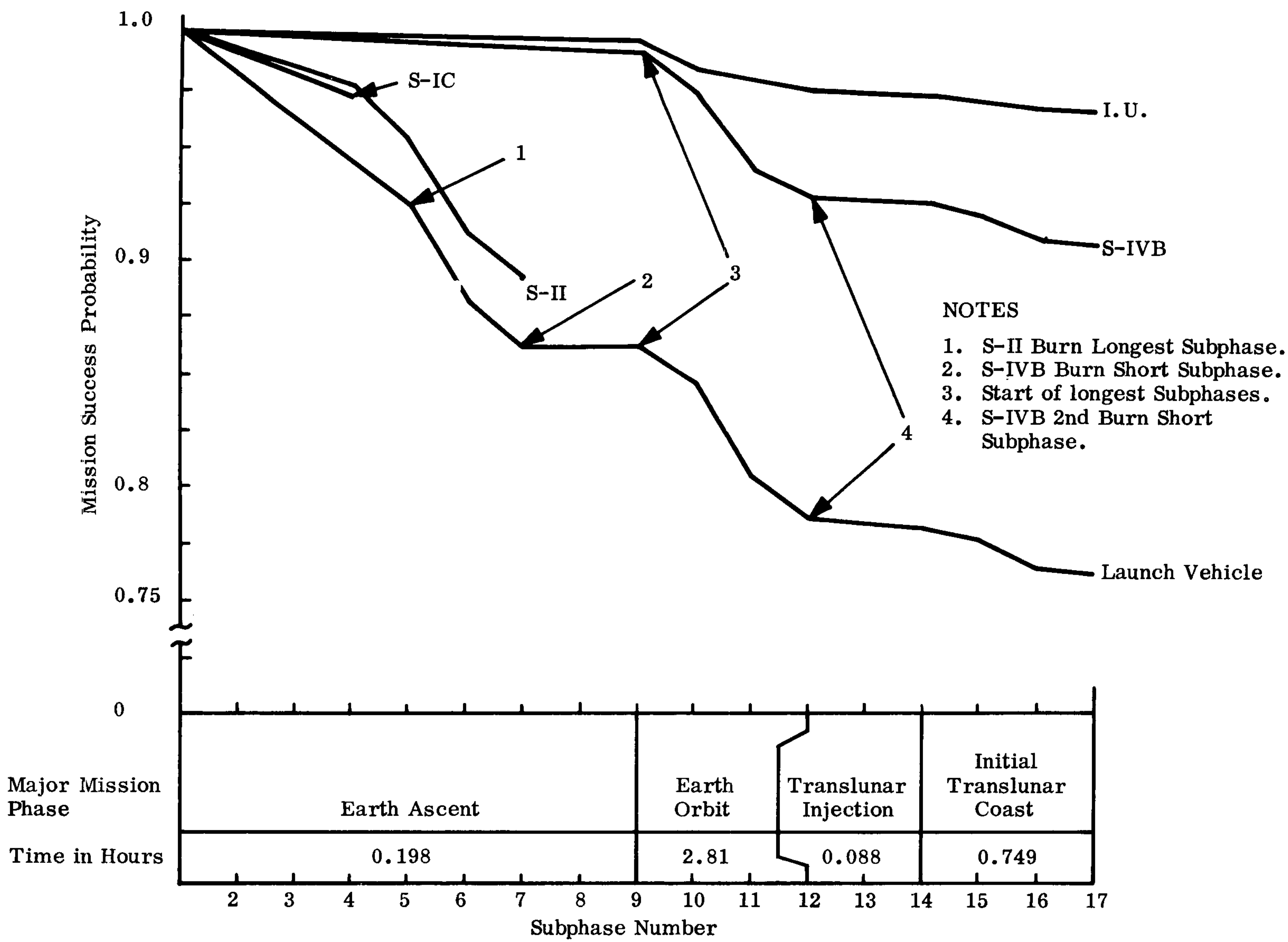


Figure 2-2. Apollo-Saturn 504 Manned Lunar Landing Mission Launch Vehicle and Stage Mission Success Probability Versus Mission Phase

unreliability of 17.6 percent. Figure 2-3 illustrates mission success probability versus major mission phases.

Values for the probability of crew safety cited in Center/contractor documents deal separately with the Command Service Module and the Lunar Excursion Module.

The Apollo Program Specification (Reference 1 of Appendix C) cites the Command Service and Lunar Excursion Module reliability apportionments (mission success goals) as 0.96 and 0.98, respectively. These figures are in agreement with the Center/contractor documented reliability apportionments (Appendix C References 42 and 52). The corresponding Center/contractor apportionment values * are 0.964 and 0.987. The product of these two numbers is 0.96.

The Apollo Program Office predictions, based on Center/contractor subsystem and component reliability predictions for the Command Service and Lunar Excursion Module are 0.766 and 0.889, respectively. The product of these two numbers is 0.68. The Center/contractor predictions for the Command Service and Lunar Excursion Module are 0.944 and 0.844 resulting in a product of about 0.83. The relatively large difference between the Center/contractor and Apollo Program Office predictions for the Command Service Module and, therefore, the Apollo Spacecraft, is considered to be a result of currently unresolved differences between Center/contractor and Apollo Program Office reliability models, data, and mission information. In particular, the Apollo Program Office considers some of the abort criteria, backup modes, and redundancies to be questionable. For example, the contractor's reliability logic diagrams of the CSM Environmental Control System incorporate the assumption that the mission will be aborted only after failure of the <u>secondary</u> suit loop compressor. The present analysis assumes that the mission will be aborted after the <u>primary</u> suit loop compressor fails. The Manned Spacecraft Center is currently working with the contractors to resolve this and similar problems concerning other spacecraft systems and subsystems.

*Numbers are rounded off.

[redacted]

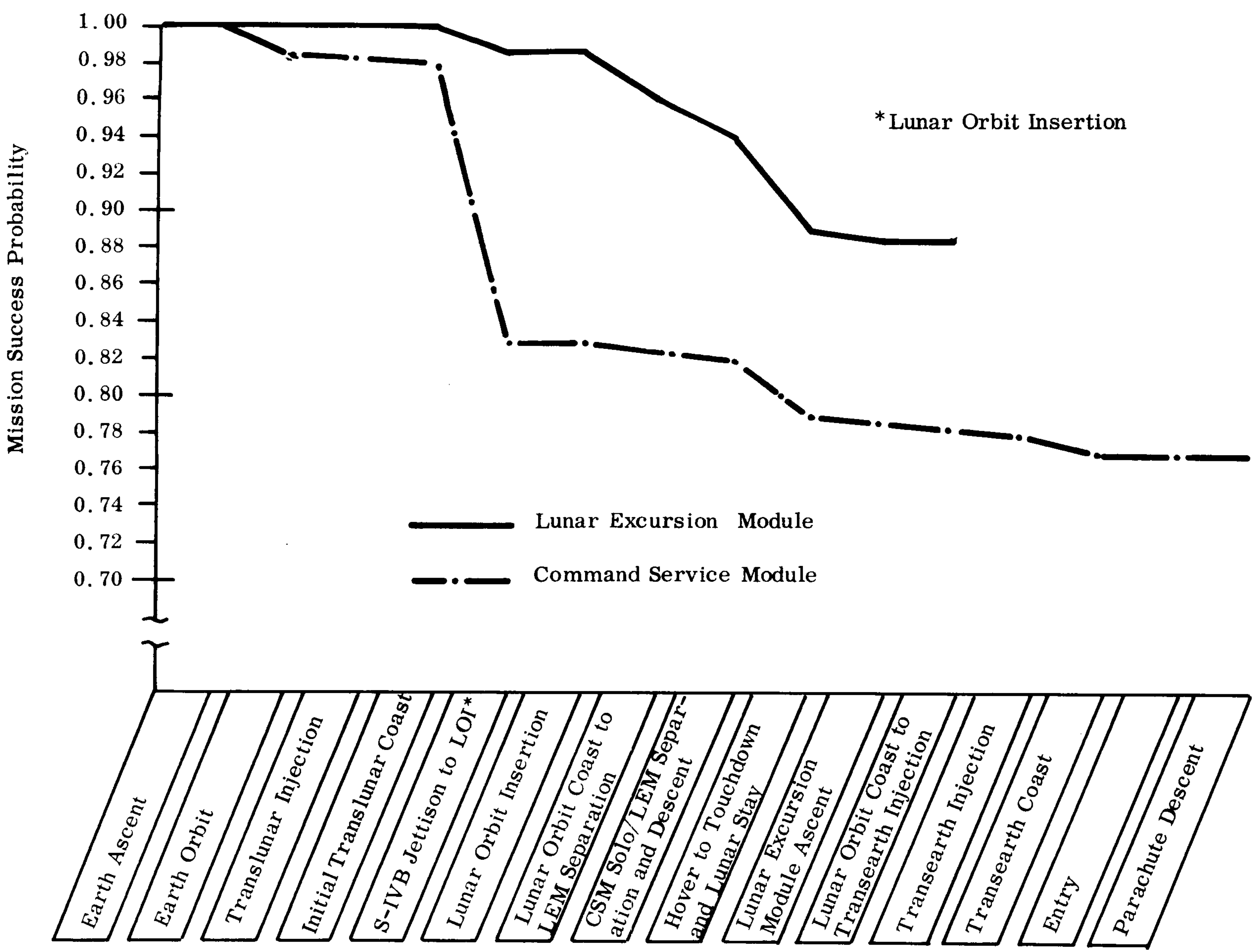
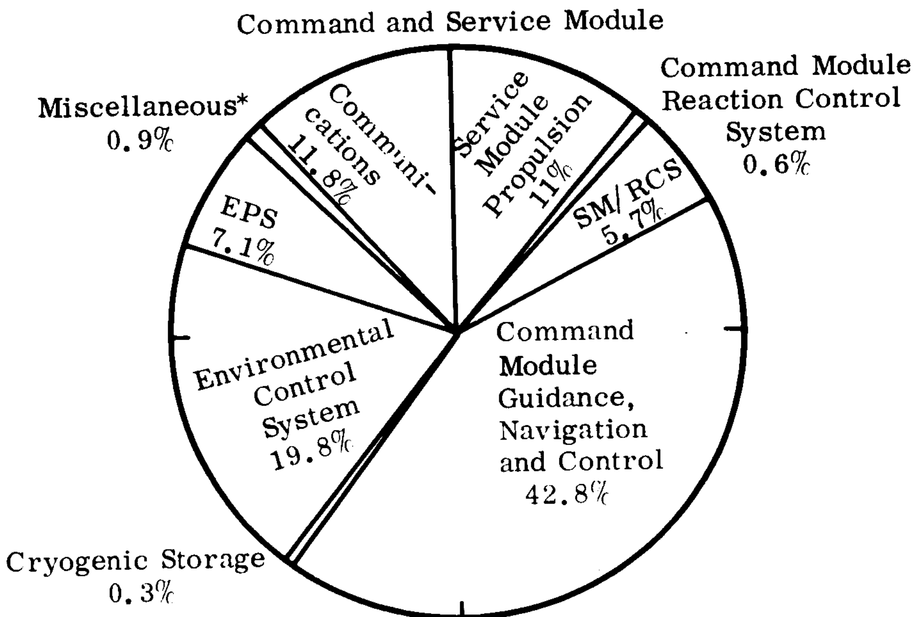


Figure 2-3. Apollo-Saturn 504 Manned Lunar Landing Mission Stage and Module Probabilities of Mission Success Versus Major Mission Phase

[redacted]

2.1.2.3.2 Command Service Module (CSM)

The Command Service Module contributes 41 percent to mission unreliability. Figure 2-4 shows the percentage contribution of systems to Command Service Module unreliability.



* Miscellaneous includes structure, emergency detection system, launch escape system, earth landing system, heat shield, and separation.

Note: 1. The Command Service Module accounts for 40.5 percent of space vehicle unreliability.
2. Ground operational support system and crew functions were considered to have a reliability of 1.0 for this study.

Figure 2-4. Apollo-Saturn 504 Manned Lunar Landing Mission Percentage Contribution of Systems to Command Service Module Unreliability

Following is a summary discussion of the reliability status of the Command Service Module subsystems. Additional information can be found in Appendix C.

CSM Guidance, Navigation, and Control - This subsystem contributes 42.8 percent to the Command Service Module unreliability. Ground rules (Reference 32 of Appendix C) dictate that the mission be aborted if any of the Guidance Navigation equipments fail prior to initiation of Lunar Excursion Module descent. This ground rule, the unreliability of the two continuously operating flight director attitude indicators and the two gyro packages, makes the Guidance Navigation and Control system of the Command Service Module the leading contributor to the probability of mission failure. Continuous operation of both indicators and gyro packages during the long translunar coast phase significantly degrades reliability. Placing the equipment in the "off" or "standby" mode during most of the translunar coast phase of the mission should be considered. A comparison of the present prediction estimate to the contractor's apportionment and prediction values cannot be made at this time as the contractor considers the Guidance, Navigation, and Control system not as a separate subsystem but as part of the Integrated Electronics system. The Apollo Program Office prediction estimate of 0.984 reflects the Guidance, Navigation, and Control subsystem as an independent portion of the module.

CSM Environmental Control System - The Environmental Control Subsystem contributes 19.8 percent of the predicted Command Service Module unreliability. Most of the system unreliability is due to leakage around the pump bearings in the water-glycol circuit. Improvements in the design are being evaluated.

CSM Communications - The Communications system contributes 11.8 percent of the predicted Command Service Module unreliability.

Communications during the translunar coast will be comparatively unreliable due to expected performance limitations on the S-band directional antenna and the S-band power amplifier. In the absence of contractor information, definitive ground rules for determining mission success were postulated for analysis purposes. The current prediction is conservative because of possibility of successfully completing a mission with degraded communications has not been considered.

Contractor apportioned and predicted mission success reliabilities are grouped under the general title of Integrated Electronics; therefore, no comparison with the Apollo Program Office prediction is possible.

Service Propulsion System - This system contributes 11 percent to the predicted Command Service Module unreliability. Combustion instabilities and the long operating time of the propellant tanks continue to degrade the reliability of the subsystem. The storage tanks, being in use for the entire mission, are the largest contributors to mission unreliability in this system.

Service Module Reaction Control System - The Reaction Control subsystem contributes 5.7 percent to the predicted Command Module unreliability. The propellant tank bladders exhibit high diffusion characteristics which are considered failures because of the resultant degradation in propellant flow and the threat of propellant explosion.

CSM Electrical Power - The Electrical Power system contributes 7.1 percent to the predicted Command Service Module unreliability. The universal inverter (Inverter No. 3) contributes most to mission unreliability in this subsystem. While continuous operation is required for most components of the Command Service Module Electrical Power system, this is not true for the static inverters. The normal operating mode for the inverters requires that Inverters No. 1 and No. 2 operate during the boost phases of launch and during each ΔV maneuver. Only Inverter No. 1 operates at all other times. Should Inverter No. 1 fail, Inverter No. 2 begins continuous operation. Should Inverter No. 2 also fail, the mission is aborted and Inverter No. 3 is used. Although only one inverter operates throughout the majority of the mission, the non-operating inverters are also subject to failure in their standby mode.

The following Block II Design will affect the reliability estimates:

a. Expected elimination of the pyrotechnic separation batteries.

b. Redesign of the present high acoustical noise static inverters used in Block I, in order to obtain a low noise Block II static inverter. This redesign is expected to cause a different failure probability for the static inverters due to addition of components.

c. Replacement of the 25-ampere hour entry and post-landing batteries by 40-ampere hour batteries. This change is expected to lessen the criticality of the battery charger.

CSM Miscellaneous Systems - The Command Service Module structures, Emergency Detection system, Launch Escape system, Earth Landing system, Heat Shield, and Separation system contribute 0.9 percent to the module unreliability. Only fixed point reliability values were available for each of these systems. There are no differences between the Center/contractor and the Apollo Program Office reliability predictions.

CSM Reaction Control System - The Command Module Reaction Control system contributes 0.6 percent to the predicted total module unreliability. The helium tanks which are pressurized for the entire mission, are the heaviest contributors to the probability of system failure. Since the propellant tanks are not pressurized until just prior to re-entry, expulsion bladders do not appear to present a reliability problem.

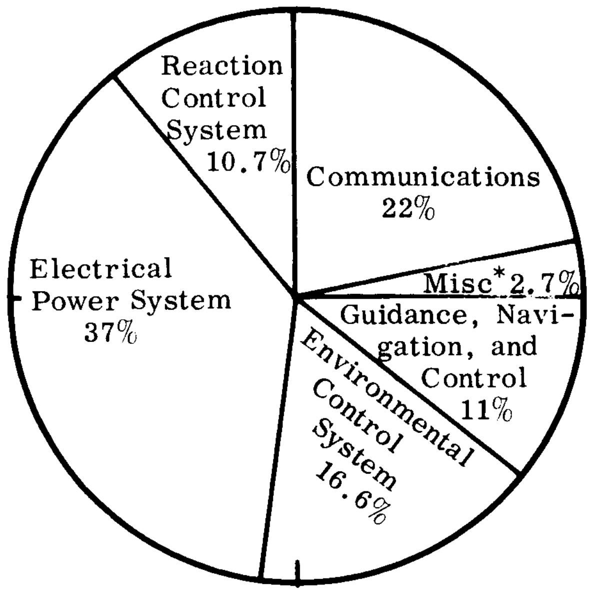
CSM Cryogenic Storage - The Cryogenic Storage system contributes 0.3 percent to the predicted Command Service Module unreliability. The equipment needed for quantity gauging is the most unreliable part of the Cryogenic Storage subsystem. Specifically, the pressure transducer and quantity probe and indicator are critical items.

2.1.2.3.3 Lunar Excursion Module (LEM)

The Center, contractor, and Apollo Program Office mission success reliability predictions for the Lunar Excursion Module are in agreement. The Lunar Excursion Module contributes 18.5 percent to the predicted mission unreliability. Following is a discussion of the reliability status of the Command Service Module subsystem. More detailed information can be found in Appendix C. The percentage contribution of systems to Lunar Excursion Module unreliability is shown in Figure 2-5.

LEM Electrical Power System - The Electrical Power System contributes 37 percent of the predicted Lunar Excursion Module unreliability. This is due to the operational ground rule requiring all four descent batteries to operate during the lunar stay period. The duration of this period (approximately 35 hours) combined with the battery failure rate accounts for 70 percent of the Electrical Power System unreliability. A lunar stay of only 20 hours, for example, would increase the probability of mission success since only three of the four descent batteries would be required.

Lunar Excursion Module



*Miscellaneous includes structure, ascent propulsion, descent propulsion, and pryotechnics.

Note: 1. The Lunar Excursion Module accounts for 18.4 percent of space vehicle unreliability.
2. Ground operational support system and crew functions were considered to have a reliability of 1.0 for this study.

Figure 2.5. Apollo-Saturn 504 Manned Lunar Landing Mission Percentage Contribution of Systems to Lunar Excursion Module Unreliability

LEM Communications - The Communications System contributes 22 percent to the predicted module unreliability. The Extra Vehicular Activity (EVA) backpack transceiver contributes most to the probability of system failure because of a high failure rate and long mission use time. The high failure rate, however, is questionable since each transceiver has two transmitters and two receivers; in addition, the total failure of one backpack receiver does not necessitate an abort of the mission but merely degrades the efficiency of conducting the lunar exploration.

LEM Environmental Control System - The Environmental Control System contributes 16.6 percent of the predicted total module unreliability. The major Environmental Control System problems are in the water-glycol circuit, the pressure suit compressor, and in the cabin recirculating blower. All three subsystems have low reliability brushless dc motors.

LEM Guidance And Control - The Guidance and Control System contributes 11 percent of the predicted total module unreliability. The abort sensor assembly contains all the inertial reference equipment and is the most unreliable component in the system.

LEM Reaction Control System - The Reaction Control System contributes 10.7 percent of the predicted total module unreliability. The propellant bladders are the most unreliable components.

LEM Miscellaneous Systems - The Miscellaneous Systems contribute 2.7 percent of the predicted total Lunar Excursion Module unreliability. The Miscellaneous Systems include the Lunar Excursion Module Structures, Ascent and Descent Propulsion, and Pyrotechnics Systems. Reliability information on these systems are limited at the time of this analysis. Fixed value reliability estimates from the Apollo Program Office data bank compare well with the contractor apportionments and predictions.

The major problem in the Ascent and Descent Propulsion Systems is the re-seating of the valves after an operational cycle. Purge and filtering techniques are being improved to alleviate this problem.

Crew Systems - The current configurations of the crew system were discussed at a recent Manned Space Flight Center Reliability Data Review Meeting. It was tentatively agreed that the Crew System and Crew Provisions should first be studied from a Failure Mode Effect Analysis and Configuration Viewpoint, before presenting the crew system elements in reliability logic diagrams. A reliability of 1.0 was assumed for the crew system and crew performance in this analysis.

2.1.2.4 Ground Operational Support System (GOSS)

The Apollo-Saturn Ground Operational Support System (GOSS), composed of the Manned Space Flight Networks (MSFN) and the Control Centers, is an information transportation system supporting the communications and tracking capabilities of the Space Vehicle. GOSS is composed of complex facilities, which will be variably configured for each mission, as well as during each mission, and they will be operated by many and diversified agencies.

In general, the Launch Vehicle support requirements from the MSFN include telemetry, tracking, and digital command communications for 6.5 hours following liftoff (lunar landing mission). The Command Service Module requirements include voice communications, telemetry, tracking, and digital command communications throughout the entire mission except during periods of thrusting. Television is specified during earth orbit and translunar coast phases. Voice communications, telemetry, and tracking are required during operation of the Lunar Excursion Module, and television is included during lunar surface operations.

GOSS support to the mission during earth orbit is limited to about one-third of the time. This is due to the GOSS station location and antenna coverage with relation to the space vehicle ground track. Launches at higher than 72 degrees azimuth, which may be either planned or result from launch delay, could result in less coverage. Mission events which are obscured by the moon cannot be directly support by GOSS.

Current recommended mission ground rules require mission abort when one or more failures would result in loss of the crew. The Block II Guidance, Navigation and Control system to be used in all manned lunar flights, and included in the present analysis, will depend on earth-based tracking. The onboard capability is retained but only as a backup. Since there are but two means of navigation, loss of either dictates an abort.

Currently, neither Center nor contractor documents indicate that apportionments and predictions include reliability aspects of associated ground based equipment.

2.1.2.5 Crew Safety And Mission Success

2.1.2.5.1 Mission and System Analysis

This analysis relates probabilistic measures of mission/system effectiveness to the 15 major phases of the Design Reference Mission and to Apollo-Saturn V Space Vehicle systems making the largest contribution to mission unreliability.

The Launch Vehicle and Spacecraft contribute about 40 percent and 60 percent, respectively, to the total unreliability for the Apollo-Saturn 504 mission. (Mission unreliability equals one minus the probability of mission success.) The operational mission time of the Launch Vehicle, however, is only about three hours compared to 198 hours for the Spacecraft. Thus, the unreliability contributions are 13.5 and 0.3 percent per mission hour for the Launch Vehicle and Spacecraft, respectively.

Figure 2-6 shows the ranking of the 15 mission phases by contribution to mission unreliability, and it indicates which system accounts for the largest share of the unreliability within that phase. Also ranked are the contributions of the phases to chance of crew loss. The transearth coast phase ranks highest in probability of crew loss. This phase spans a longer time period (88 hours) than any other phase. In this portion of the mission there is no alternate route to the landing area and, after approximately first midcourse correction thrusting in this phase, neither primary nor secondary mission abort capability exists. Consequently, mission failure in this phase is synonymous with crew loss. This condition is reflected in the high safety hazard rank.

The S-IVB Jettison to lunar orbit insertion phase is the prime contributor to mission unreliability. This phase also ranks high (second) in relative safety hazard. This condition is due to abort criteria and abort duration. Abort criteria for the Command Module Guidance and Navigation System require that the mission be aborted if any of the Guidance and Navigation system equipments fail. Once initiated, abort from this phase extends over a long flight path and requires continued use of the system whose partial failure caused the abort.

The general assumptions applied to the equipments and functions in the formulation of the Apollo-Saturn 504 Mission simulation model are listed as follows.

a. At the instant of liftoff, all space vehicle systems and their equipments are operating properly.

b. Nominal flight trajectories and nominal environmental conditions both external and internal to the space vehicle prevail, and nominal system performance levels are attained by nonfailed systems and equipments throughout the mission.

Mission Phase	Leading System Contributor to Mission Unreliability	Rank by Phase Contribution to Mission Unreliability	Rank by Relative Safety Hazard
Earth Ascent	S-II Stage	2	12
Earth Orbit	S-IVB Stage	3	11
Translunar Injection	S-IVB Stage	13	14
Initial Translunar Coast	S-IVB Stage	6	13
S-IVB Jettison to Lunar Orbit Insertion	CSM(1) Guidance, Navigation and Control	1	2
Lunar Orbit Insertion	Service Propulsion	12	7
Lunar Orbit Coast to LEM Separation	LEM(2) Electrical Power	5	10
CSM Solo/LEM Separation and Descent	LEM Reaction Control	7	4
Hover to Touchdown and Lunar Stay	LEM Electrical Power	4	3
Lunar Excursion Module Ascent	LEM Guidance and Navigation	10	6
Lunar Orbit Coast to Transearth Injection	CSM Environmental Control	9	9
Transearth Injection	CSM Guidance, Navigation and Control	11	5
Transearth Coast	CSM Environmental Control	8	1
Entry	CM(3) Reaction Control	15	12
Parachute Descent	CSM Miscellaneous Systems	14	8

(1) Command Service Module
(2) Lunar Excursion Module
(3) Command Module

Figure 2-6. Phase and System Criticality Rankings

This assumption was applied to the following items:

(1) Flight crew functions.

(2) Ground operational support system.

(3) Oxygen supply (Descent), Lunar Excursion Module environmental control.

(4) LiOH cartridge, Lunar Excursion Module environmental control.

(5) Portable life support system cartridge, Lunar Excursion Module environmental control.

(6) Ground support equipment disconnect, Lunar Excursion Module environmental control.

(7) Line of Sight/Velocity Indicator, Lunar Excursion Module guidance, and control.

(8) LiOH cannister check valve, Command Service Module environmental control.

(9) Backup roll attitude display, Command Service Module guidance, navigation, and control.

(10) Entry monitor display, Command Service Module guidance, navigation and control

c. Systems, equipments, or functions for which reliability data were either unavailable or inapplicable were assigned a reliability of 1.0.

2.1.2.5.2 Reliability Apportionment And Prediction Estimates

Differences between the reliability apportionments and the reliability predictions for Launch Vehicle Stages and Spacecraft Modules are ranked, below, in order of decreasing magnitude.

System	Difference (*)
Lunar Excursion Module	+0.103
S-II Stage	+0.057
S-IVB Stage	+0.040
S-IC	-0.026
Instrument Unit	+0.024
Command Service Module and Adapter	+0.020
Ground Operational Support	Unknown

Reliability apportionment and prediction values at the over-all mission and stage/module level are tabulated in Appendix C (separately bound).

Based upon Center/contractor reliability apportionments, the estimates of mission success and crew safety probabilities are 0.96 and 0.73, respectively, as reported in the previous Quarterly report dated 9 July 1965 (Reference 4 of Appendix C).

Apollo Program Office estimates of crew safety and mission success probabilities, based on current Center/contractor reliability predictions, are shown as a function mission time in Figure 2-7. The major causes of the degradation of probability values and the names of the mission phases are noted in this figure. The Apollo Program office predicted crew safety and mission success probabilities for the manned lunar landing mission are 0.96 and 0.52, respectively.

2.1.3 APOLLO-SATURN RELIABILITY PROGRAM STATUS (Figure 2-8)

2.1.3.1 Qualification Test Summary

Qualification test of all launch vehicle critical components is to be completed prior to Apollo-Saturn 501. The detailed qualification status of each stage is discussed in Paragraphs 2.2 through 2.5. The status of testing relating to the Spacecraft and LEM is reported in Paragraphs 2.6 and 2.7. Figure 2-9 depicts over-all Apollo-Saturn V component qualification status.

(*) Rounded to three decimal places.

[redacted]

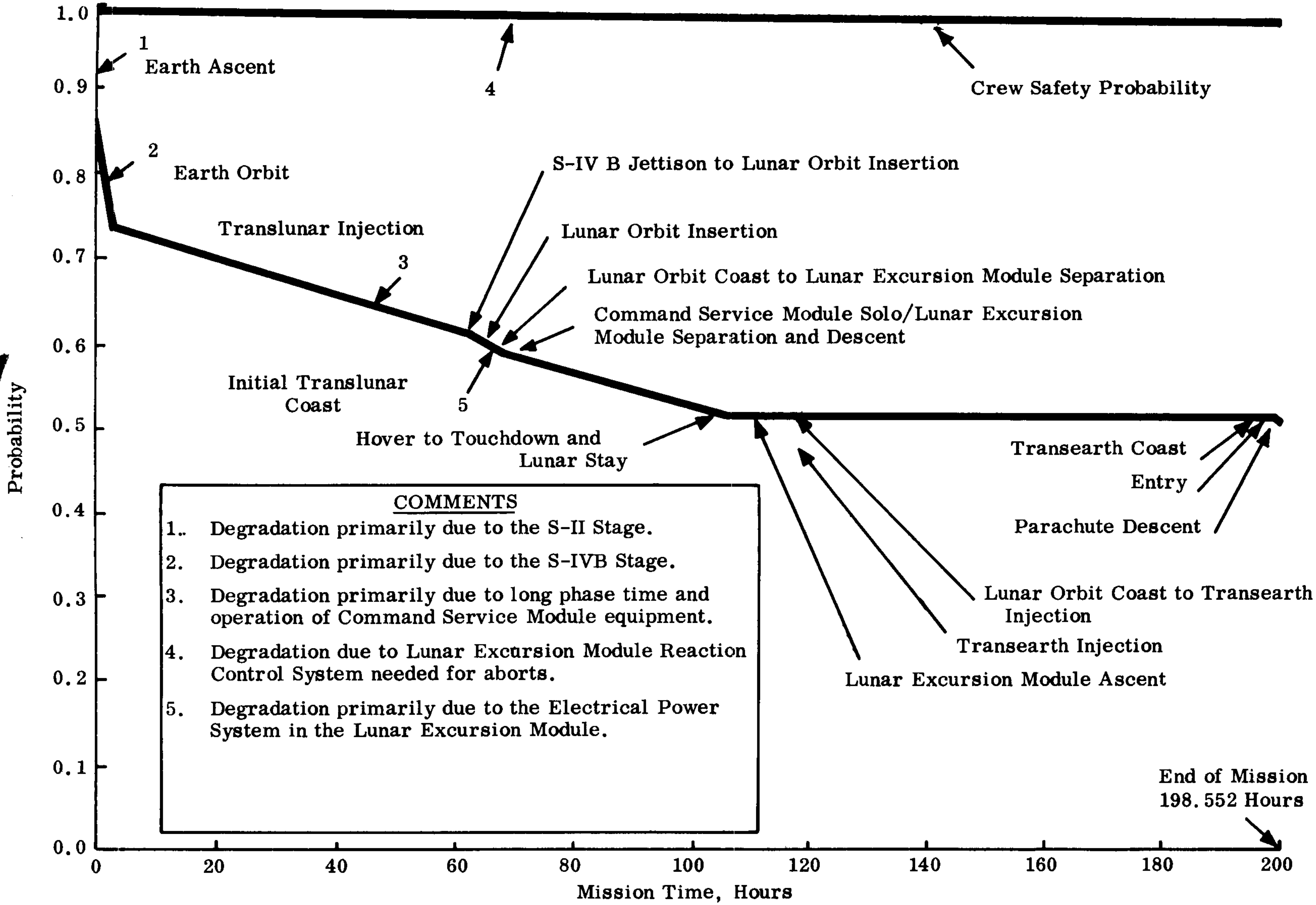


Figure 2-7. Mission Success and Crew Safety Probabilities Versus Time

[redacted]

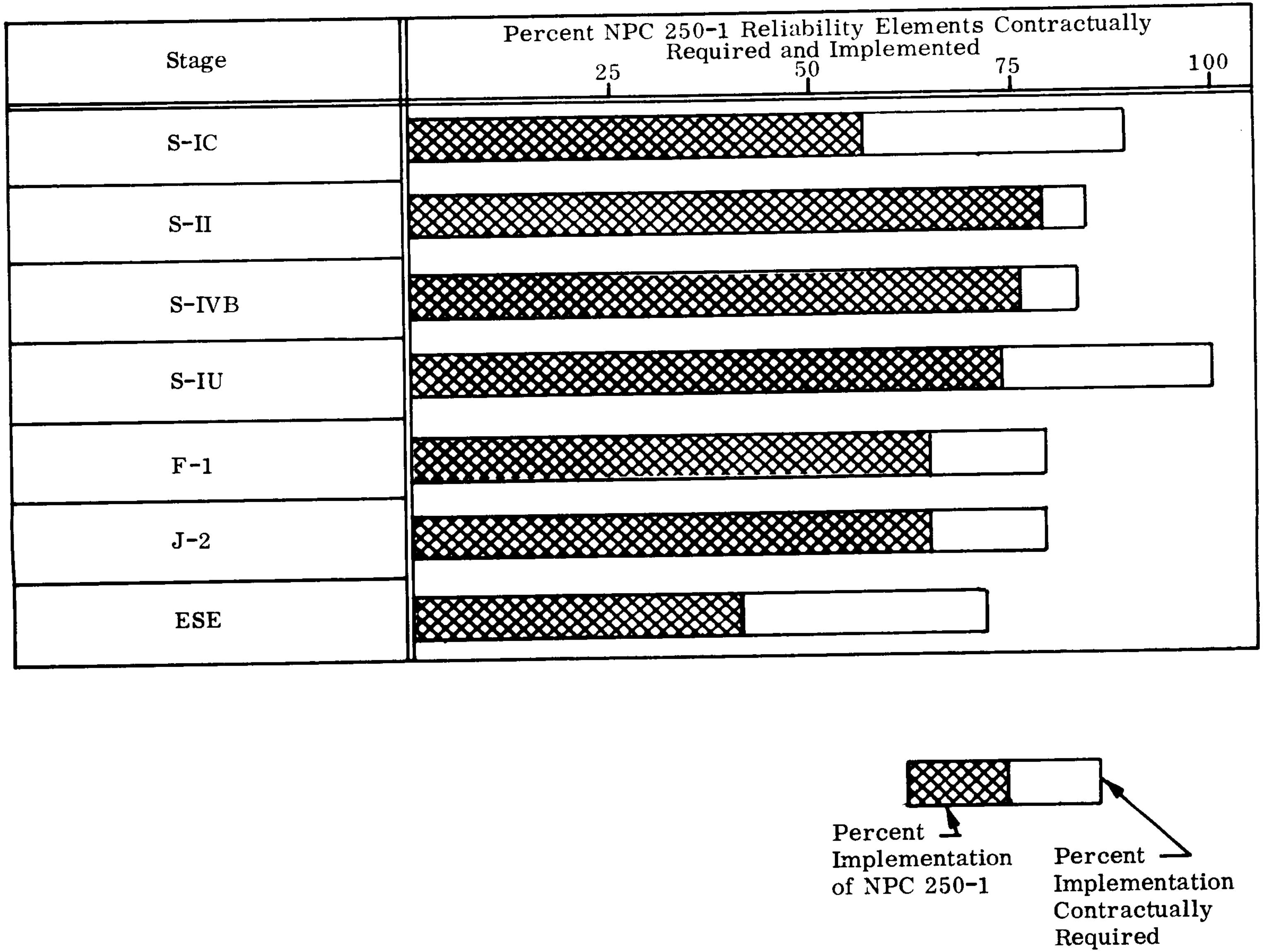


Figure 2-8. Saturn V Program Summary Reliability Assurance Evaluation Based on NPC 250-1

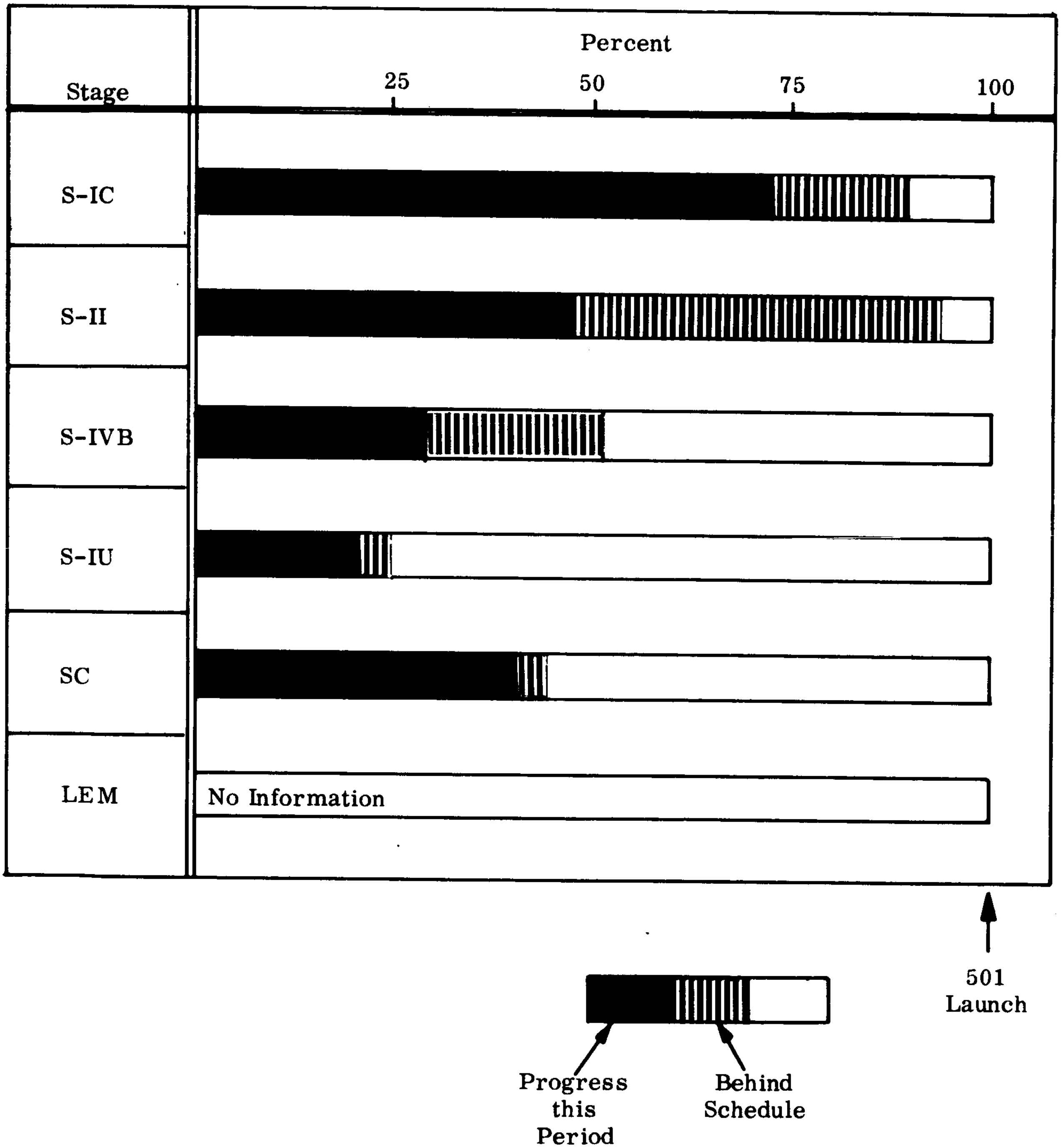


Figure 2-9. Apollo-Saturn V Component Qualification Status

2.1.3.2 Ground Support Test

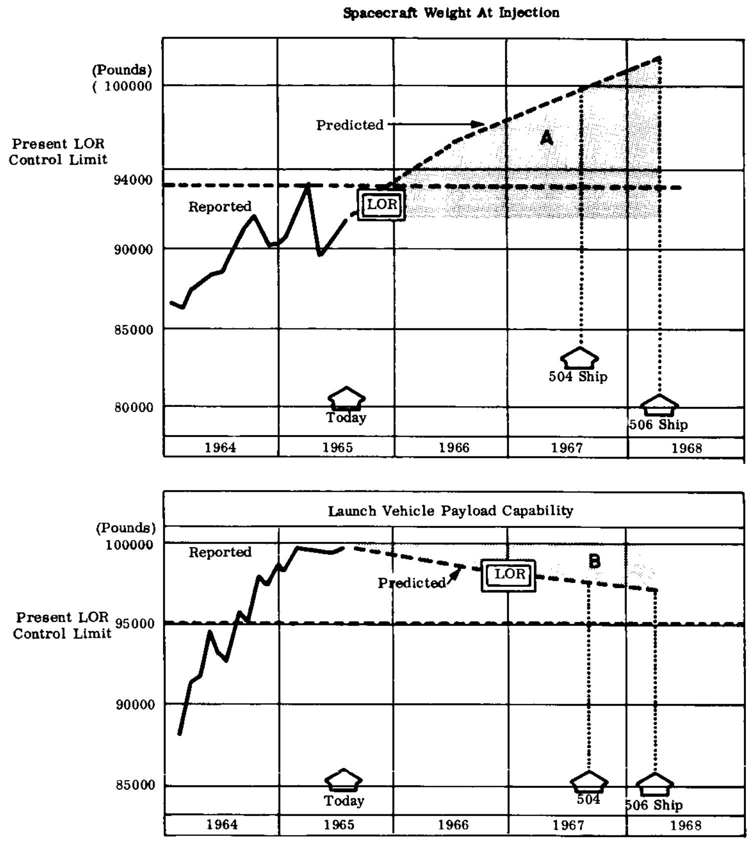
Current ground testing in support of the Apollo-Saturn 504 Mission is largely restricted to developmental testing. Tests in support of specific Apollo-Saturn 504 Mission constraints have not yet been identified.

Based upon development testing to date, it appears that the pacing item for the launch vehicle is the S-II Stage. The development problems being experienced on the S-II Stage are essentially quality and process control problems. It is anticipated that this area will require continuing reliability and quality scrutiny throughout the life of the program.

The Bell Aerosystems bladder development and test program continues to bear significantly on Apollo-Saturn V reliability and is under careful scrutiny by all affected contractors and Centers. The bladders are to be used in the Spacecraft Reaction Control Systems (CSM and LEM) and in the Auxiliary Propulsion System of the S-IVB. Various techniques for reducing stress and friction are being studied and tested.

2.1.3.3 Weight Considerations

Current weight-capability predictions point to a 2,000-pound difference between payload weight and launch vehicle payload capability for the Apollo-Saturn 504 Mission. The difference between the current trend of spacecraft weight growth and the growth of launch vehicle payload capability (as of August 1965), depicted in Figure 2-10, indicates reasons for concern. Shaded areas A and B of Figure 2-10 portray the weight growths. Reported LEM Ascent and LEM Descent inert weights increased significantly in August. The over-all LEM now exceeds its 32,000-pound control limit by 67 pounds and is still increasing. Center/contractor activities are continuing in an effort to improve this situation.



Note The 504 Launch Vehicle capability for LOR mission is higher than that reported for the 504 L/V by MSFC due to assumed removal of the R&D equipment which weighs 5796 pounds in the S-IC stage and 1775 pounds in the S-II stage.

The 504 Launch Vehicle capability shown above is for the LOR mission. For an earth orbital mission, payload capability would be increased substantially over that shown.

Figure 2-10. Spacecraft Weight at Injection Versus Launch Vehicle Payload Capability

2.1.3.4 Apollo-Saturn 501 Mission

The mission directive for the Apollo-Saturn 501 has not yet been issued nor have the test constraints been defined. Launch vehicle critical problems affecting the Apollo-Saturn 501 mission are as follows:

a. The qualification test program is delayed and behind schedule due to development problems and lack of component hardware availability.

b. The S-II-1 is behind schedule due to insulation problems.

c. Launch Complex 39 GSE (including ESE) is behind schedule.

d. The time required for redesign and rework of Crawler-Transporter bearing assemblies may cause slippage of the Apollo-Saturn 501 launch date.

2.2 S-IC STAGE

2.2.1 GENERAL

2.2.1.1 Summary

During this report period, the S-IC Stage continued in the ground test phase. The "Saturn S-IC Reliability Program Plan" was revised and updated as of May 1965. Reliability effort was directed toward establishing the reliability of design. The basic design release for the S-IC-1 Stage was completed in June 1965. However, there have been continuing changes in instrumentation. Urgent changes relating to the Stage/F-1 Engine interface are also in process.

2.2.1.2 Milestones

Figure 2-11 reflects current S-IC Stage reliability and quality assurance program milestones. All milestones through 1 July 1965 were completed on schedule with the exceptions of: (1) Updating D5-12572-2 "Integrated S-IC System Design Analysis" (rescheduled for 1 October 1965), and (2) completing development of the computer program (previously rescheduled to August 1965).

2.2.1.3 Reliability Program

Reliability program status as of 9 August 1965 is shown in Figure 2-12. It should be noted that certain NPC 250-1 requirements do not apply at this stage of the program. Therefore, not all the elements have been 100 percent invoked.

Contractor audit of all organizations (for compliance with the Reliability Program Plan) is conducted quarterly. Audit results have been summarized in S-IC Reliability Program Status Documents, D5-12604-3, D5-12955-1, and D5-12955-2.

The "Saturn S-IC Parts Selection and Control Plan," D5-11372, has been issued and is being implemented. A total of 30 management reviews and quality system surveys were conducted at supplier facilities by the beginning of this quarter.

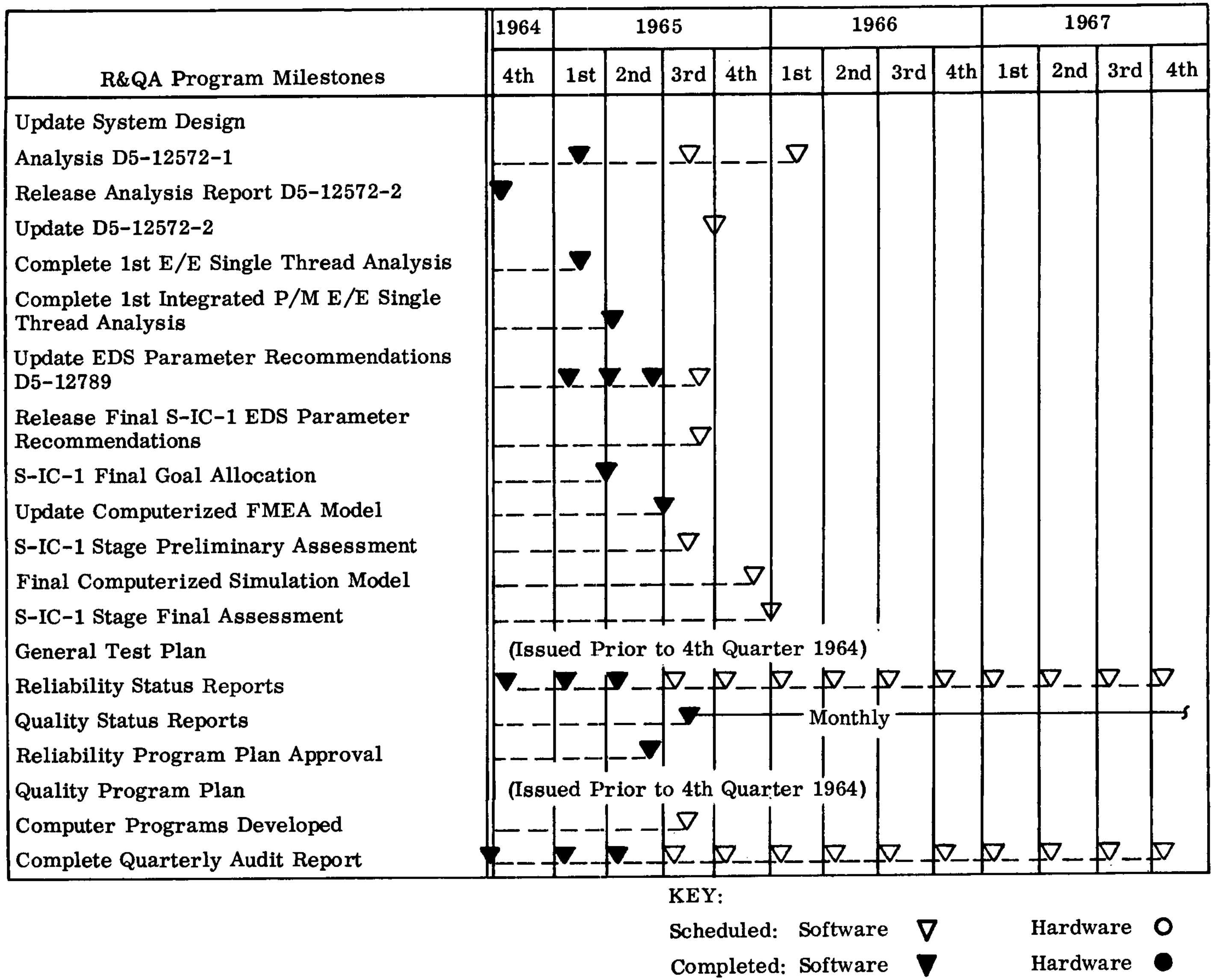


Figure 2-11. S-IC Stage Reliability and Quality Assurance Milestones

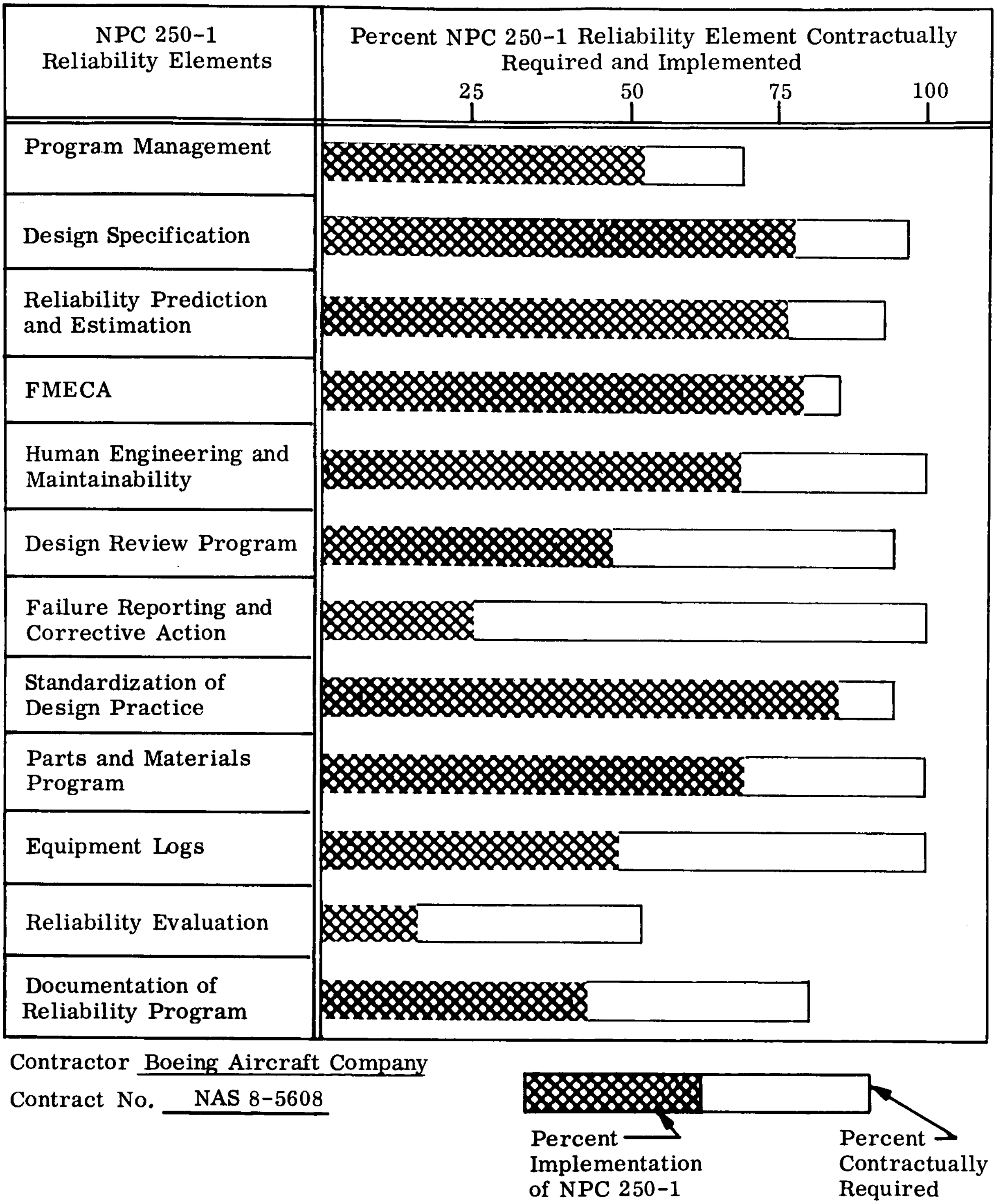


Figure 2-12. S-IC Stage Reliability Assurance Evaluation Based on NPC 250-1

2.2.2 RELIABILITY ENGINEERING

2.2.2.1 Design

Basic design release of the S-IC-1 has been completed. However, there have been continuing changes in instrumentation requirements. Propulsion and instrumentation systems designs have also been increasingly affected by F-1 Engine changes.

The "Propulsion/Mechanical Systems Design Analysis" was updated to include the control pressure system design change. The "Operational Electrical Systems Design Analysis" was released. The Electrical/Electronic systems were integrated into the Single Thread Analysis diagram.

Major leaks and failures of gimbals and flex hose have been eliminated as valid failure modes by revised analysis ground rules from NASA/MSFC R-P&VE-VO. The Boeing Company reports that the "S-IC Single Thread Analysis" (D5-12289) has been updated to reflect the change.

This ground rule change results in a limited single thread analysis since major failure effects such as "LOX tank rupture due to overpressure" do not appear.

Three design changes affecting flight article reliability have been identified; they are as follows:

a. S-IC-1 - Two LOX depletion sensors will be disconnected for Apollo-Saturn 501 and subsequent vehicles.

b. S-IC-4 - Provisions for increased propellant loading to achieve ten seconds more flight time will be achieved.

c. S-IC-4 - Incorporation of a redesigned fuel expulsion system will be accomplished.

The reliability effect of each change is being studied.

2.2.2.2 Critical Parts

The "Ten Most Critical Parts" for the S-IC stage are depicted in Figure 2-13. These have been derived from the "Saturn V Reliability Analysis Model, SA-501" and should be considered preliminary.

Item	Subsystem	Critical Ranking by Flight Stage			
		S-IC 501			
Retro-Rocket Motor	Retrorocket	1			
Engine 4-Way Control Valve	F-1 Engine	2			
Prevalve	Fuel Delivery	3			
Gimbal Duct LOX	LOX Delivery	4			
Gas Gen. Ball Valve	F-1 Engine	5			
Main Oxidizer Valve	F-1 Engine	6			
Prevalve, N.O., Outboard LOX	LOX Delivery	7			
Turbine, Internal Leak	F-1 Engine	8			
Turbine, External Leak	F-1 Engine	9			
Gimbal Duct Fuel Suction	Fuel Delivery	10			
	REF.	29			

Items Dropped from Preceding List:

Rank	Item

Figure 2-13. S-IC Stage Ten Most Critical Items

2.2.2.3 Mathematical Models

Boeing document D5-11954 "Saturn S-IC Stage Reliability Assessment and Prediction Program" was revised (12 August 1965) to update the assessment technique and partially revised to include the Multi-failure Math Model Technique. Results from the revised model will be reported in the next quarterly issue of D5-11954-1, "Saturn S-IC Stage Reliability Analysis Record."

2.2.2.4 Apportionment and Prediction

The S-IC Stage predictions shown in Figure 2-14 were obtained from the Saturn V Program Office. The S-IC Stage predictions reported in paragraph 2.1.2 of this report are contained in Appendix C hereto.

2.2.3 TEST PROGRAM

2.2.3.1 Ground Test Program

The S-IC-D vertical assembly was completed at Michoud. The first automatic firing of the S-IC-T was delayed until October due to the late completion of manual testing. Cumulative firing time on the S-IC engine was 214 seconds as of 1 July 1965.

Reliability program testing has previously been keyed to delivery of S-IC-T to MILA in late 1967. Present understanding is that the test program is to be keyed to the S-IC-3. This will require substantial compression of test schedules and deletion or consolidation of test requirements.

Hardware to be subjected to reliability testing is determined by FMEA's. All critical items will be subjected to reliability test except where similar families of hardware exist. In such cases, only the representative "worst case" will be subjected to testing. Hardware for all identified tests is presently being procured and testing has begun.

2.2.3.2 Qualification Test

The current status of S-IC component qualification testing is shown in Figure 2-15. As of 1 September 1965, 17 percent of the items to be qualified were behind schedule.

[redacted]

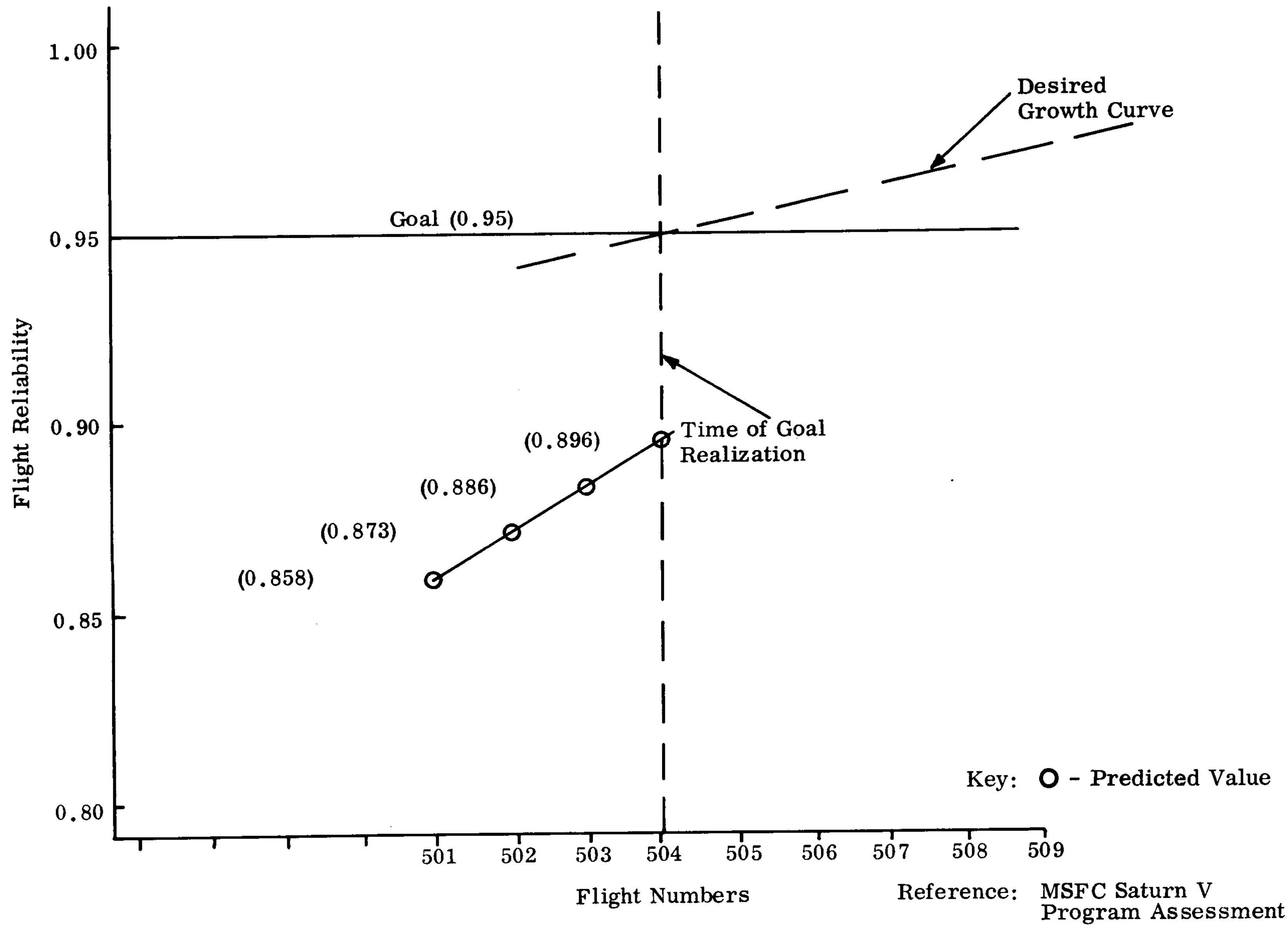


Figure 2-14. S-IC Stage Reliability Predictions

[redacted]

[redacted]

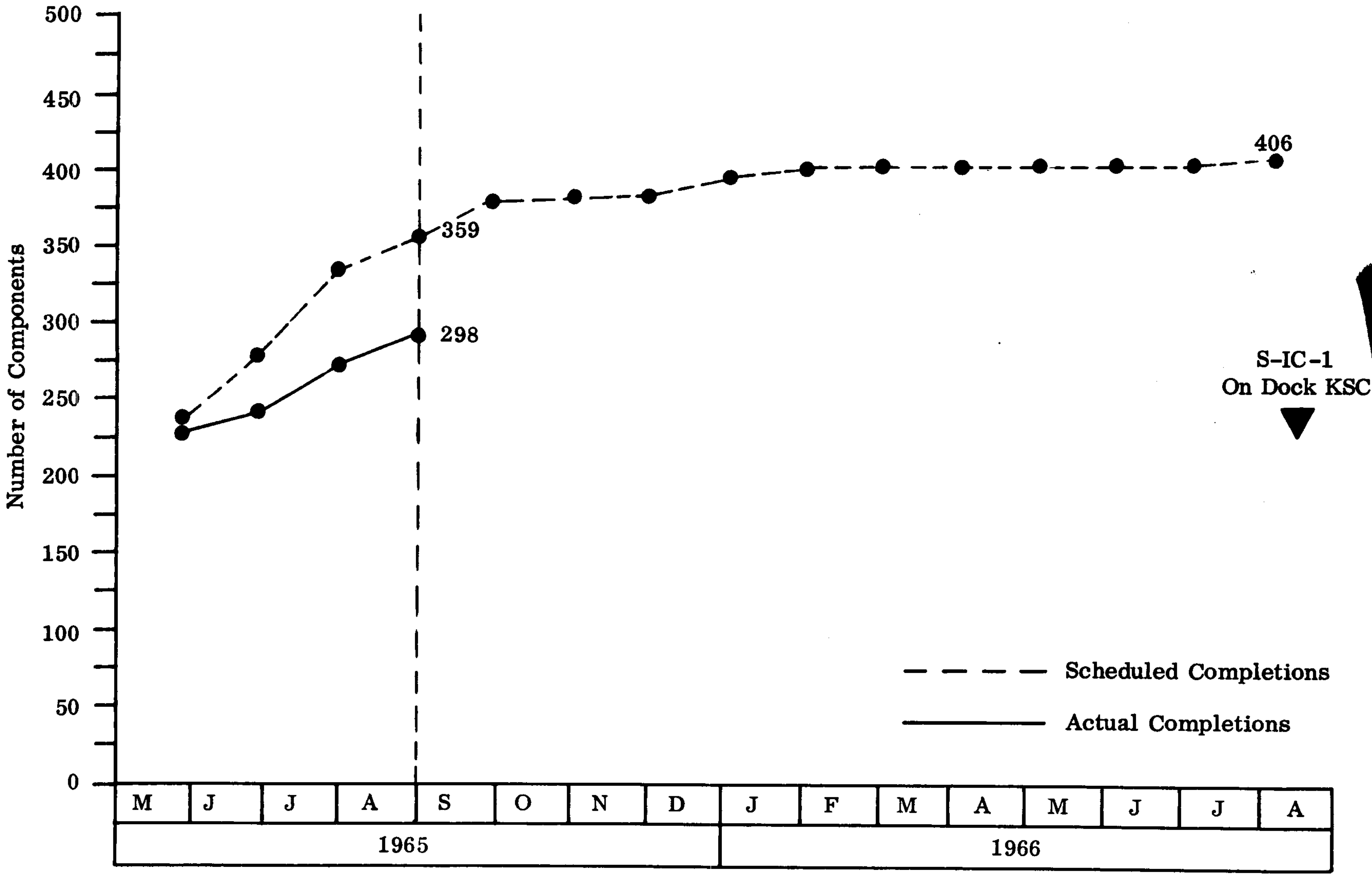


Figure 2-15. S-IC-1 Total Component Qualification

[redacted]

2.2.4 QUALITY ASSURANCE

Figure 2-16 shows reported factory failures (as of July 1965) on the indicated stages.

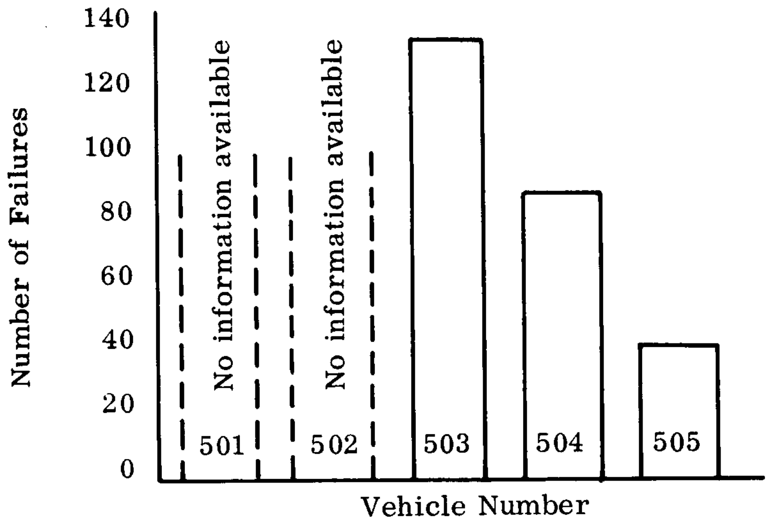


Figure 2-16. S-IC Factory Failures as of July 1965

Figure 2-17 shows the trend in percent defective parts at final assembly of the F-1 engines.

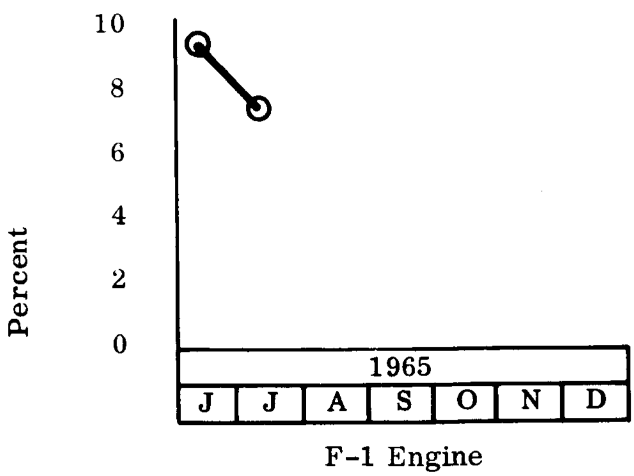


Figure 2-17. Percent of Parts Discrepant at Final Assembly

Figure 2-18 shows F-1 Engine discrepancies detected at E&M Inspection. The totals include both pre- and post-firing E&M.

NOTE

These are identified as failures by the contractor but, in most cases, are not test stand failures.

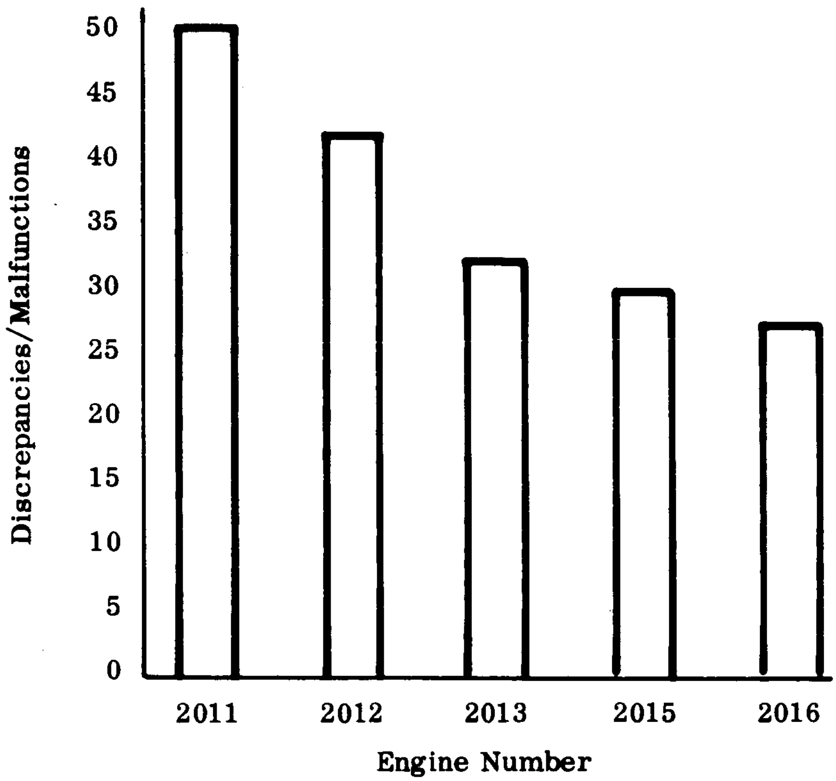


Figure 2-18. Discrepancies/Malfunction (Failures) at E&M Inspection F-1 Engines

Figure 2-19 shows the number of discrepancies noted by MSFC incoming inspection on indicated F-1 Engines. The first number in each box is the engine number. The second number is the number of discrepancies. Center GA personnel at Rocketdyne are actively pursuing a program of improved preship inspection to reduce the steady number of incoming discrepancies at MSFC. This is particularly important since plans are underway to ship future engines GFE from Rocketdyne to the stage contractors.

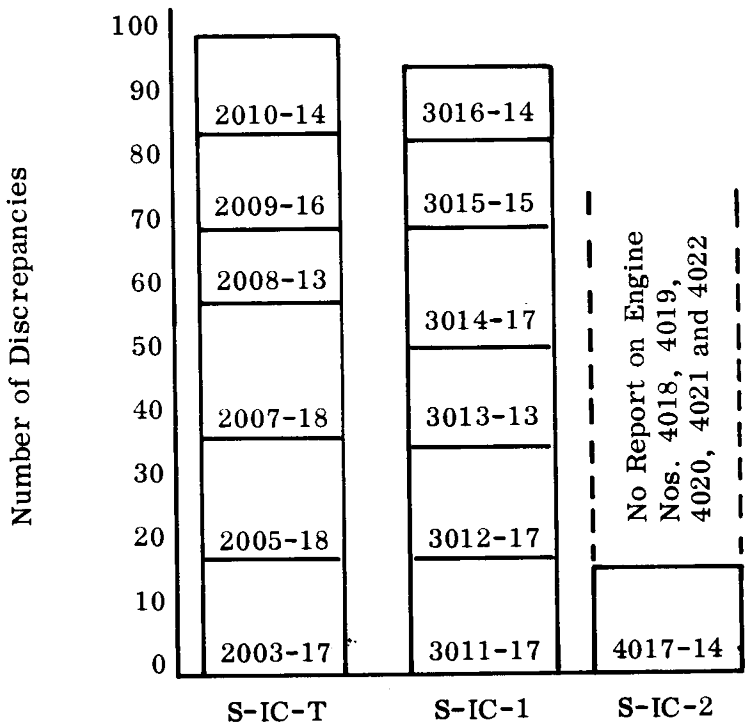


Figure 2-19. Engine Discrepancies at MSFC Incoming Inspection

[redacted]

2.3 S-II STAGE

2.3.1 GENERAL

During this report period, three battleship firings were conducted at Santa Susana. The battleship stage failed to pass the 20 second firing milestone due to insulation problems. The S-II Stage is currently one of the critical pacing items for the Apollo-Saturn 501 vehicle.

2.3.1.1 Milestones

A Quality Program plan was issued in May 1964. Monthly Quality Status Reports were issued in June and July 1965.

2.3.1.2 Reliability Program

Reliability Program status as of 9 August 1965 is shown in Figure 2-20. It should be noted that certain NPC 250-1 requirements do not apply at this stage of the program. Therefore not all program elements have been 100 percent invoked.

2.3.2 RELIABILITY ENGINEERING

2.3.2.1 Design

As was previously reported, repeated insulation failures have occurred. The cause of failure appears to be rooted in improper process specifications and inadequate in-process inspection procedures. Action is being taken to resolve the difficulty. If the corrective action is not effective, schedules of the S-II-1 may be adversely affected.

2.3.2.2 FMECA

The contractor (North American Aviation) has completed a failure mode analysis for the S-II Stage. The "Ten Most Critical Items" list (Figure 2-21) was derived from the Saturn V Reliability Analysis Model, SA-501 and based on separately performed criticality analyses.

[redacted]

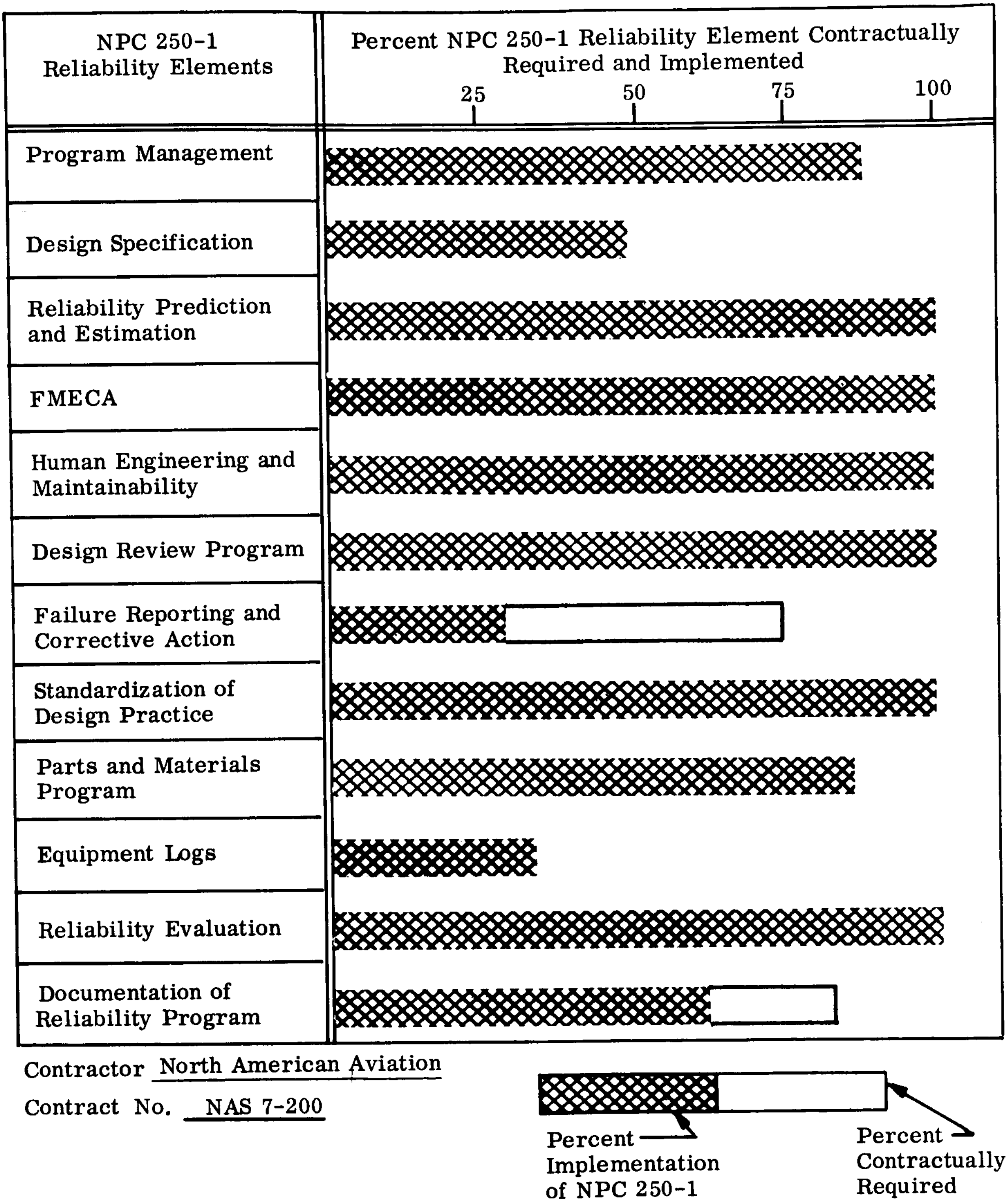


Figure 2-20. S-II Stage Reliability Assurance Evaluation Based on NPC 250-1

[redacted]

Items	Subsystem	Critical Ranking by Flight Stage			
		S-II 501			
Wire Harness Assembly (207W1)		1			
J-2 Engine Control Circuit		2			
Switch Selector Harness		3			
Recirculation Control Circuit		4			
Static Inverter (ME495-0006)		5			
Prevalve Control Circuit		6			
Connectors (Harnesses 219W6, 216W14, 206AW3, 206W16)		7			
Pressurization Control Circuit		8			
Connectors (Harnesses 206W208, 206A7W3, 216W15, 219W5)		9			
Connectors (Harnesses 206W16, 206A7W7)		10			
	REF.	29			

Items Dropped from Preceding List:

Rank	Item

Figure 2-21. S-II Stage Ten Most Critical Items

[redacted]

2.3.2.3 Mathematical Models

Reliability Prediction, Assessment, and Apportionment Documents have been prepared for the S-II Stage. The prediction model is described in North American Aviation S&ID document, SID 62-1369, the assessment model is described in SID 63-469, and apportionments are described in SID 62-1225.

2.3.2.4 Apportionment and Prediction

The North American Aviation "Reliability Goal Status Summary" portrays continued erosion of reliability goals due to NASA and NAA instituted changes and variations in the program. The largest erosion (-0.034207) is ascribed to the engine. The "Current Indicated Goal" for the S-II Stage is thus indicated to be 0.909470 versus the "Initial Apportioned Reliability Goal" of 0.950000.

Predictions for the S-II Stage shown in Figure 2-22 were obtained from the Saturn V Program Office. The S-II Stage Predictions reported in Paragraph 2.1.1 of this report are contained in Appendix C hereto.

2.3.3 TEST PROGRAM

2.3.3.1 Ground Support Test

Battleship firing of the S-II-T Vehicle commenced in July 1965 and is scheduled for completion by the end of the year.

2.3.3.2 Qualification Test

The current status of S-II component qualification testing is shown in Figure 2-23. As of 1 September 1965, 49 percent of the items to be qualified were behind schedule.

2.3.4 QUALITY ASSURANCE

Figure 2-24 shows the trend in Material Review Board Actions per 1000 manufacturing hours during fabrication and assembly of S-II Stages.

Considerable difficulty was experienced with forward common bulkhead welding. The greatest proportion of defects occurred in the initial 10 to 12 inches of the weld pass

[redacted]

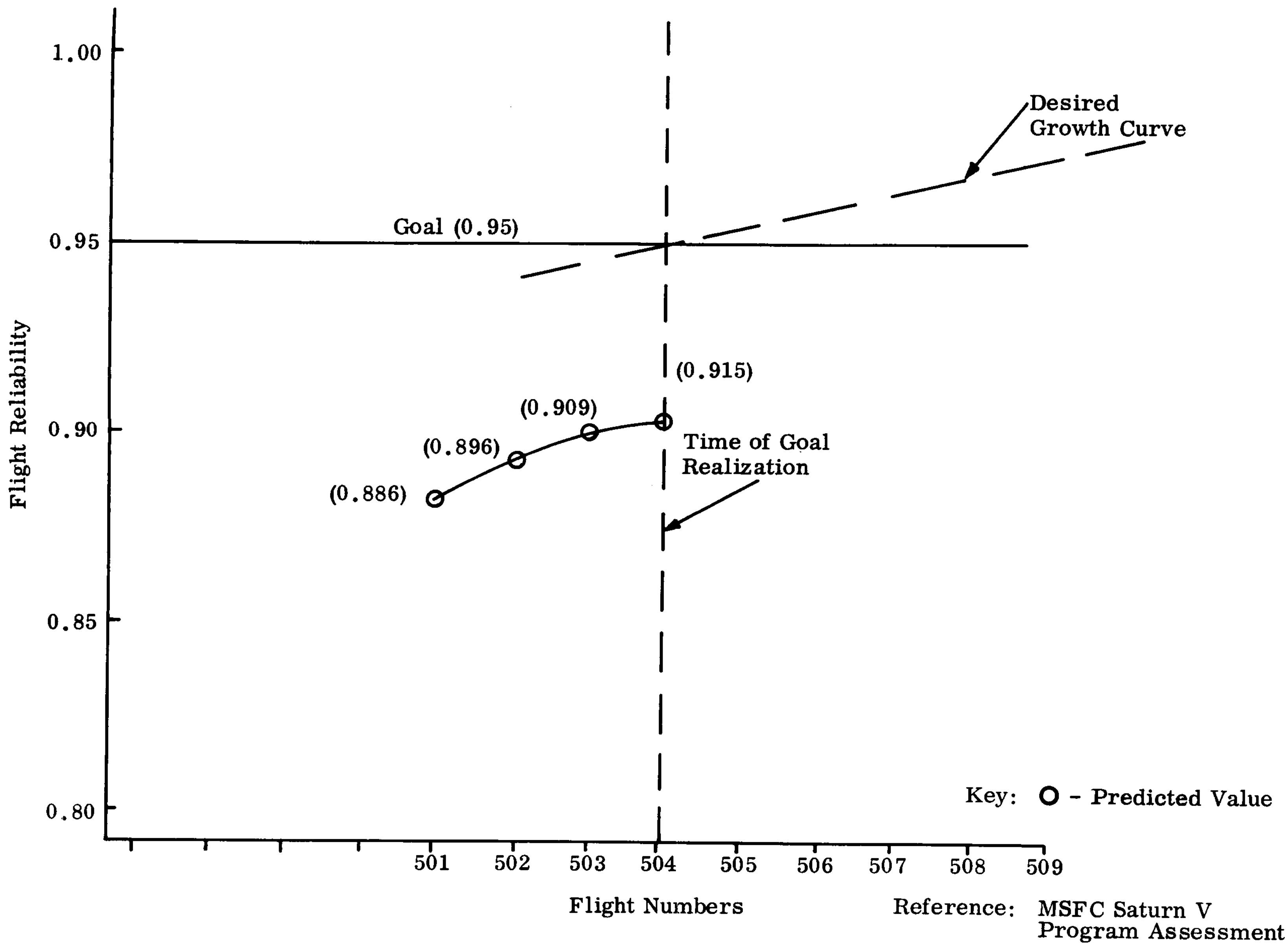


Figure 2-22. S-II Stage Reliability Predictions

[redacted]

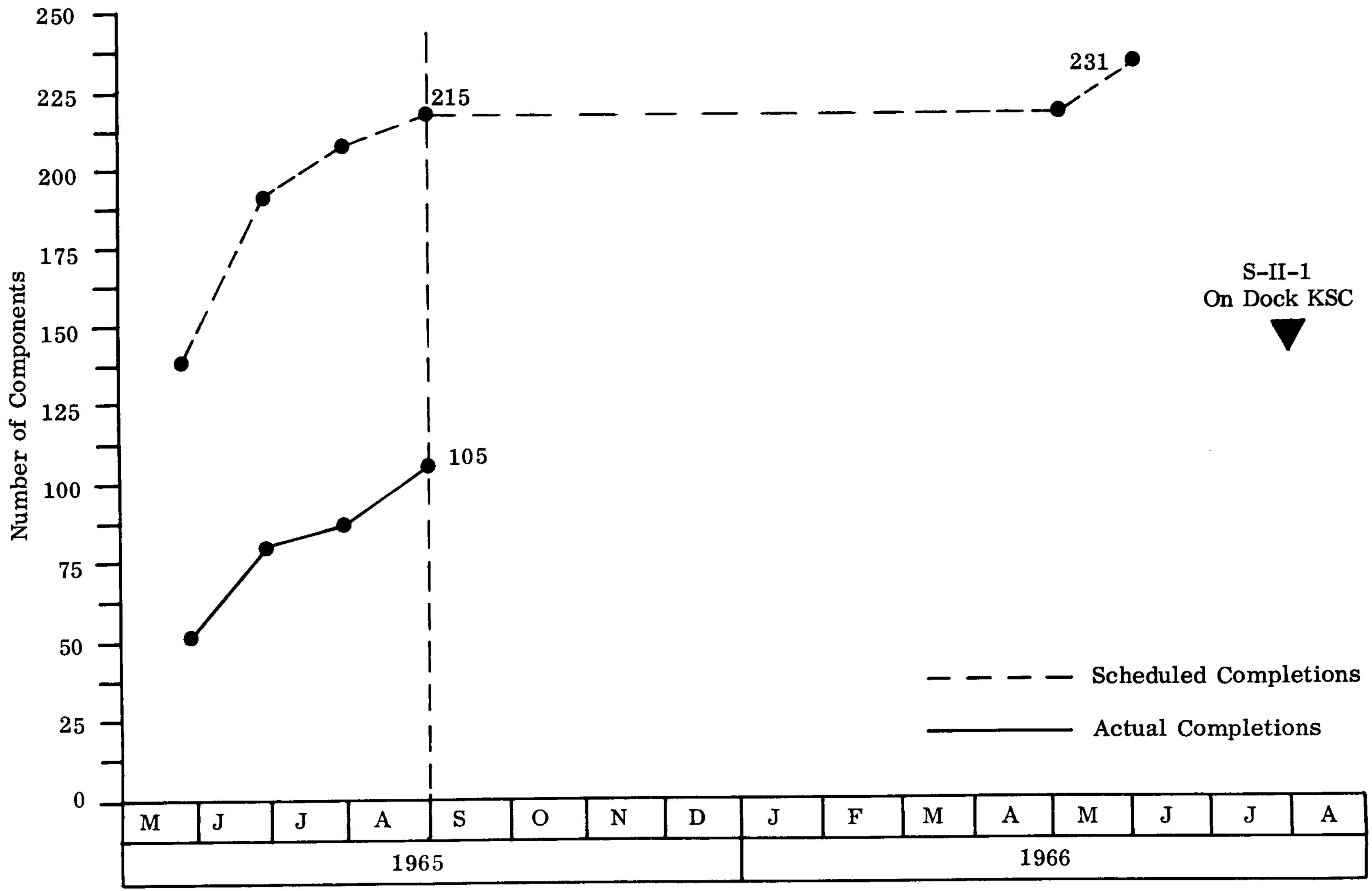


Figure 2-23. S-II-1 Total Component Qualification

[redacted]

and were primarily inclusions and porosity. New welding techniques appear to have nearly eliminated this problem.

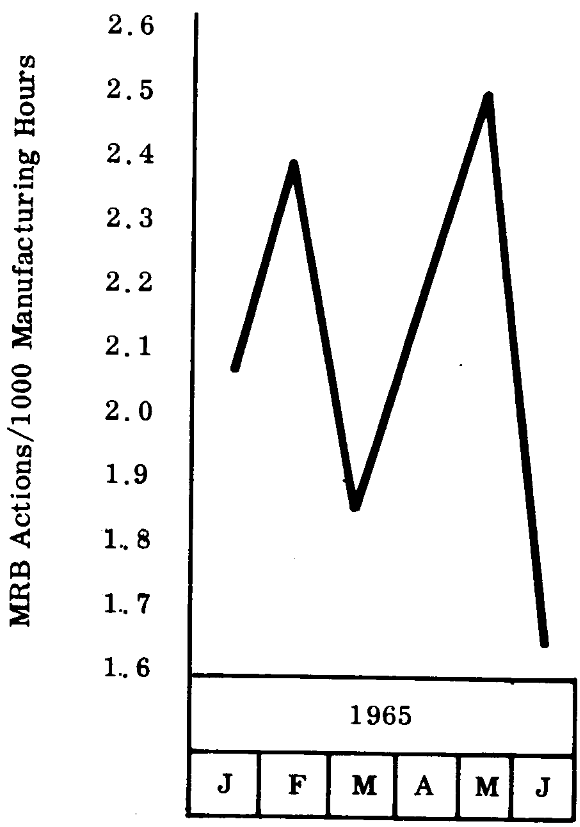


Figure 2-24. S-II Material Review Board Actions per 1000 Manufacturing Hours

2.4 S-IVB STAGE

2.4.1 GENERAL

Reliability and quality activity pertinent to the 200 series S-IVB Vehicles is reported in Section 1. This section of the report is devoted to reliability and quality assurance activity on the 500 series S-IVB Vehicles (S-IVB/V). Status reported here should be viewed as an extension of that activity reported in Section 1.

[redacted]

The S-IVB-501 is scheduled for delivery to KSC on 31 July 1966. The first Douglas prediction for the S-IVB/501 does not occur until the last quarter of 1965. The first Douglas assessment for the S-IVB/V is scheduled for the first quarter of 1966, just prior to static firing of the S-IVB-501 Vehicle.

2.4.1.1 Milestones

Reliability and quality assurance milestones for the S-IVB program are keyed against stage delivery dates. The schedule and current status of the S-IVB/V are shown in Figure 2-25.

2.4.1.2 Reliability Program

Reliability Program survey results are presented in Section 1, Figure 1-21.

2.4.2 RELIABILITY ENGINEERING

2.4.2.1 Design

S-IVB/V basic design reliability activity is related to the 200 series program. A most significant program development affecting S-IVB/V reliability is that associated with the Auxiliary Propulsion System bladder. Development problems at Bell Aerosystems are affecting the S-IVB/V as well as the LEM and CSM. S-IVB/V Auxiliary Propulsion System development engineering tests are scheduled to start in October; whereas, slosh and vibration tests presently being accomplished by Bell for the LEM may not be available in time to be utilized in the S-IVB/V design.

2.4.2.2 FMECA

Criticality analyses of the S-IVB/V have been performed. The criticality rankings resulting therefrom have been utilized in the Supplemental Reliability Mathematical Model, Saturn S-V/S-IVB Stage. The list of the ten most critical items shown in Figure 2-26 were derived from the Saturn V Reliability Analysis Model SA-501 (dated 7 September 1965) and should be considered preliminary.

[redacted]

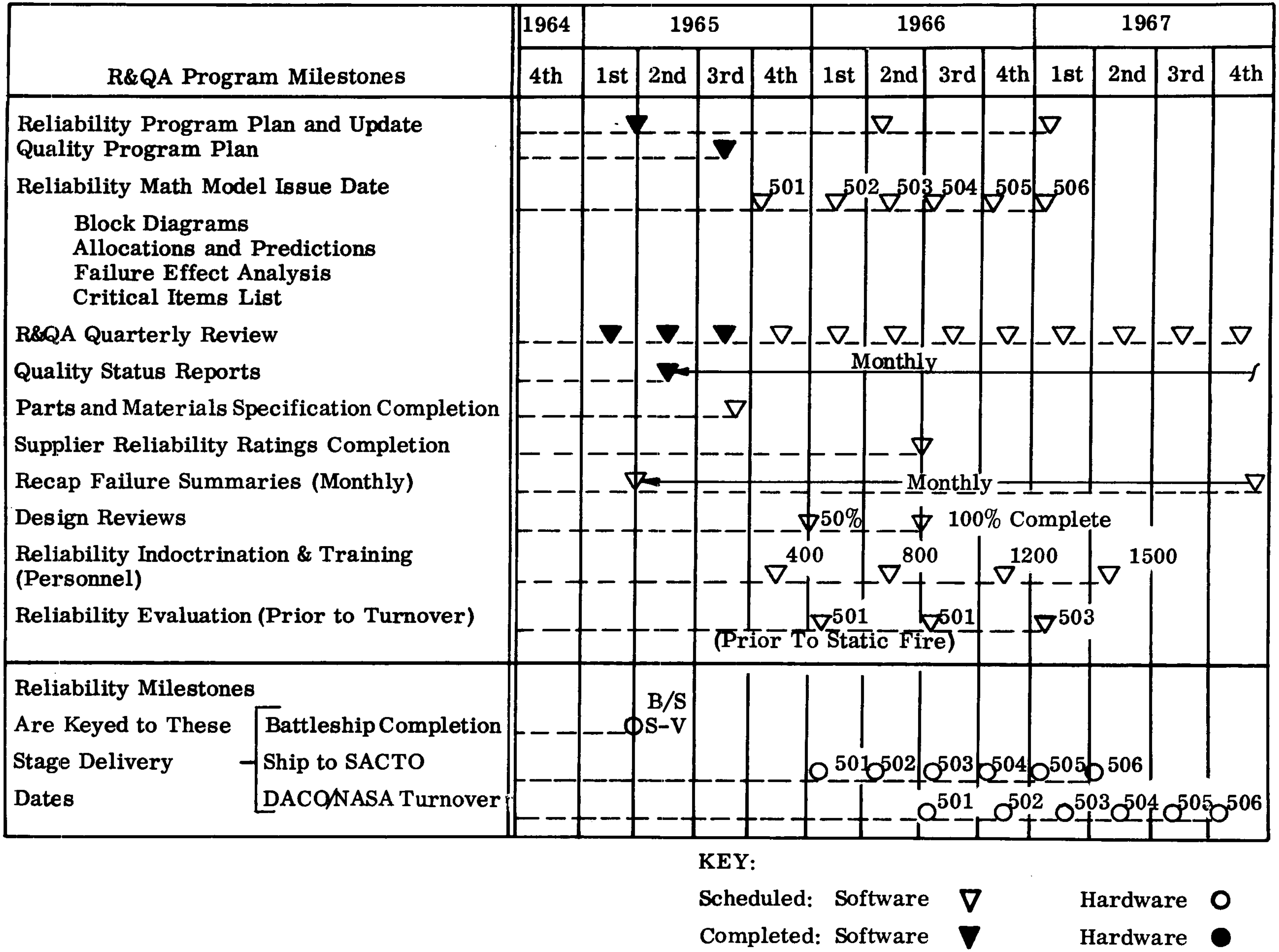


Figure 2-25. S-IVB-V Stage Reliability and Quality Assurance Milestones

[redacted]

Item	Subsystem	Critical Ranking by Flight Stage			
		S-IVB501			
Switch Selector	Electrical Command	1			
Subsystem Ducting	Hydraulic Power Supply	2			
Fuel Tank Vent System Tubing	Fuel Tank Pressure Relief and Vent Control	3			
Oxidizer Tank Prepress and Flight Control Pressure Switch	Propellant Pressurization	4			
Electric Motor	Hydraulic Power Supply	5			
Helium Dump Valve, Solenoid Operated	Attitude Control	6			
Fuel Tank Vent and Relief Valve	Fuel Tank Pressure Relief and Vent Control	7			
Helium Supply Shutoff Valve	Oxidizer Pressurization	8			
Oxidizer Pressurization Helium Relief Valve	Oxidizer Pressurization	9			
Pressure Relief Valve	Attitude Control	10			
	REF.	29			

Items Dropped from Preceding List:

Rank	Item

Figure 2-26. S-IVB Stage Ten Most Critical Items

2.4.2.3 Mathematical Model

The "S-V/S-IVB Reliability Math Model" was issued as DAC Report SM 43610, dated 15 April 1963 and revised 15 April 1964. The Math Model for S-IVB-501 is scheduled for completion in the fourth quarter of 1965.

2.4.2.4 Apportionment and Prediction

Predictions for the S-V/S-IVB shown in Figure 2-27 were obtained from the Saturn V Program Office. The S-IVB Stage predictions reported in Paragraph 2.1.2 of this report are contained in Appendix C hereto.

2.4.3 TEST PROGRAM

2.4.3.1 Ground Support Test

During the month of June 1965, three battleship firings were conducted for a total firing time of 185 seconds. Restart testing was included. Fire in the engine thrust structure caused delay in completion of the Saturn V firings. On 17 August 1965, a successful three-orbit simulation battleship firing was conducted at SACTO. The first firing was for 186 seconds, followed by a simulated 95 minute coast period and a subsequent 318 second burn after restart.

The J-2 Engine FRT series has been completed. Deficiencies uncovered during the test program are now being assessed. No impact on the flight engines is anticipated.

2.4.3.2 Qualification Test

As of 20 August 1965, qualification of S-IVB/V components was 48 percent behind schedule (See Figure 2-28).

2.5 INSTRUMENT UNIT

2.5.1 GENERAL

2.5.1.1 Milestones

Figure 2-29 describes current Instrument Unit R&QA milestones.

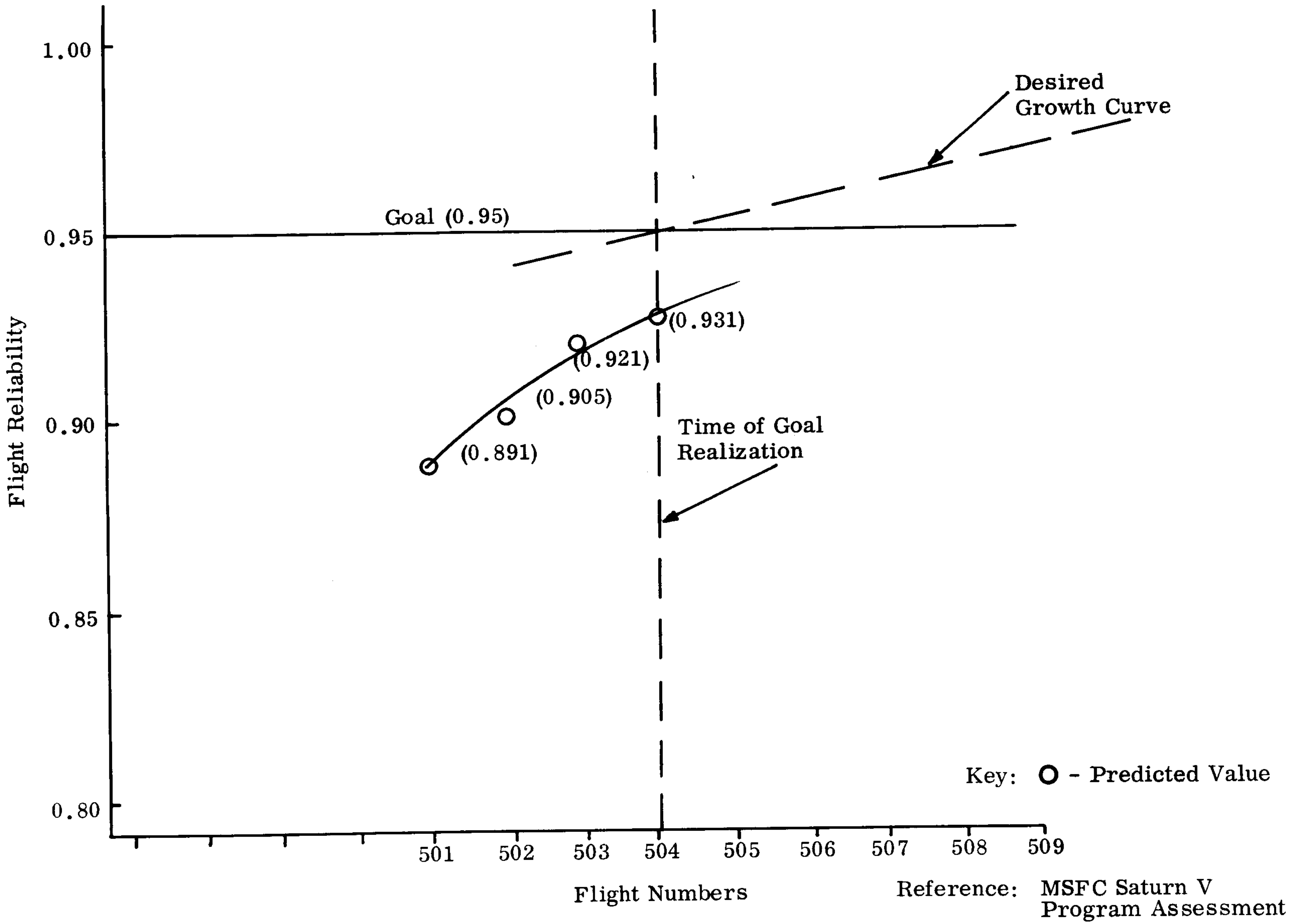


Figure 2-27. S-IVB Stage Reliability Predictions

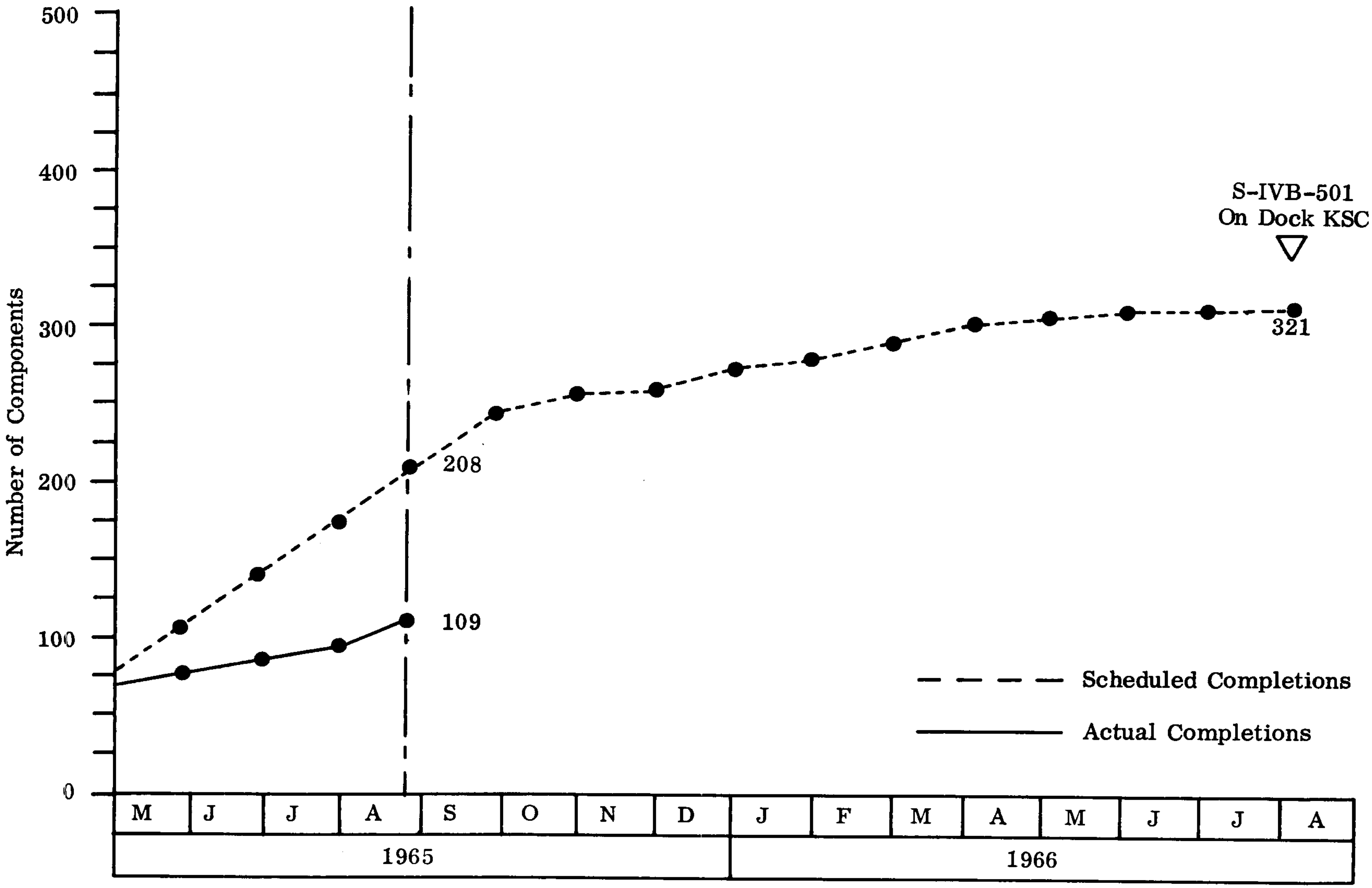


Figure 2-28. S-IVB-501 Total Component Qualification

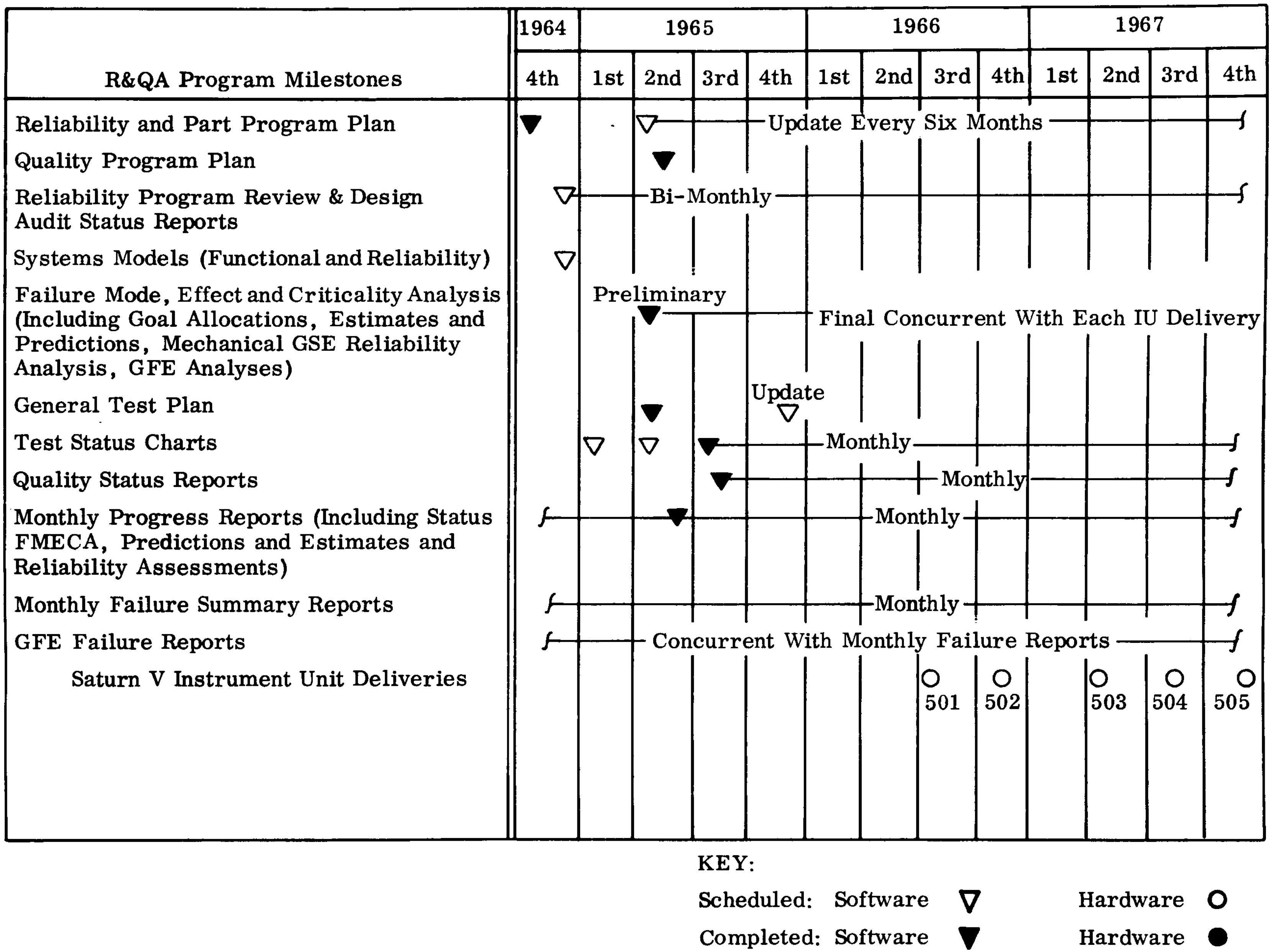


Figure 2-29. S-IU-V Stage Reliability and Quality Assurance Milestones

[redacted]

2.5.1.2 Reliability Program

The over-all IU program is developmental in nature and, as such, must rely on the more immediate gains in order to accomplish the long-range program objectives. It, therefore, follows that basic IU development is presently being conducted with primary attention focused, at this point in time, on the 200 series mission essential hardware. Section 1, of this report, outlines reliability program activities associated with the basic development program. As further progress is made toward 500 series hardware development, this section will be expanded.

2.5.2 RELIABILITY ENGINEERING

MSFC has prepared a criticality ranking for S-IU-501 and the ten most critical items are shown in Figure 2-30. As noted previously, this listing has been derived from the Saturn V Reliability Analysis Model SA-501 and should be considered preliminary.

2.5.3 TEST PROGRAM

IU component qualification test status is shown in Figure 2-31. As of 1 September 1965, 17 percent of the items to be qualified were behind schedule.

2.5.4 QUALITY ASSURANCE

IBM has reported the following problems in the Launch Vehicle Digital Computer:

a. Memory Module failures have occurred during vibration tests. These are being investigated. Reallocation of memory modules is planned to minimize schedule delays.

b. Recurrent separation of teflon insulation from the conductor has caused production to be halted on new printed circuit cables having a wider conductor (0.055 to 0.075 inch) in the cable termination area. Because the manufacturer has not yet been able to solve this problem, cables of the original design will be produced while process changes for the new design are evaluated.

c. Tests on memory cores from different stages of plan manufacturing reveal cracked cores are prevalent after X-Y, F-1, and F-2 plane tests. No cracks were found in 6,700 cores tested from lot No. 016 before the cores were vibrated into the matrix. The effects of vibration on cores will be the subject of a planned evaluation.

Item	Subsystem	Critical Ranking by Flight Stage			
		S-IU 501			
Inertial Platform	Guidance	1			
Thermal Conditioning	Environmental Control	2			
Battery (D-10)	Electrical	3			
Battery (D-20)	Electrical	4			
Platform Electronics Assembly	Guidance	5			
Launch Vehicle Digital Computer	Guidance	6			
Gas Bearing Supply	Environmental Control	7			
Electrical Distribution	Electrical	8			
Launch Vehicle Data Adapter	Guidance	9			
Platform AC Power	Guidance	10			
	REF.	29			

Items Dropped from Preceding List:

Rank	Item

Figure 2-30. S-IU-V Stage Ten Most Critical Items

[redacted]

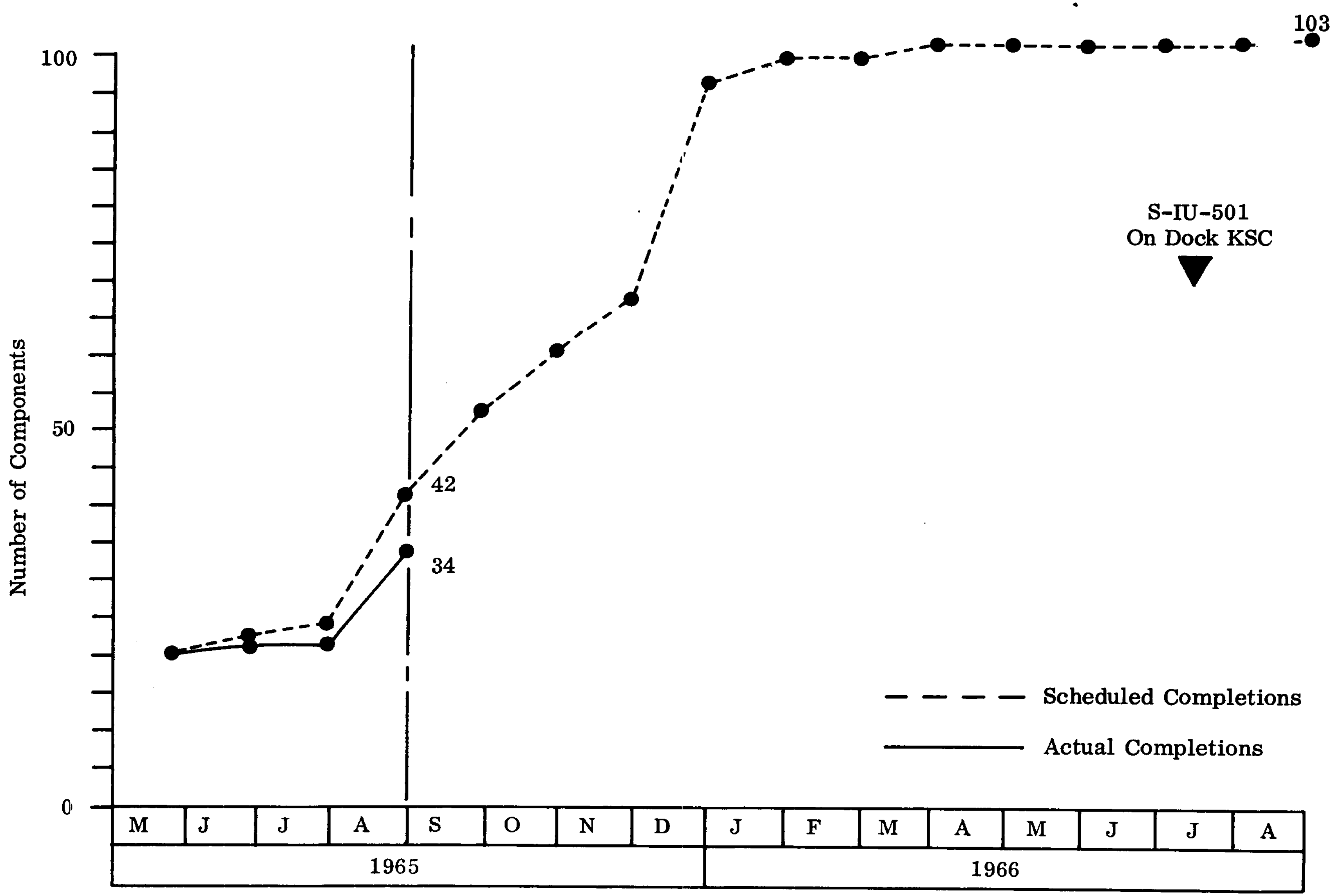


Figure 2-31. Saturn-IU-V Stage Total Component Qualification

[redacted]

IBM has reported the following problems in the Launch Vehicle Data Adapter: During vibration testing of the LVDA Triple Modular Redundant Number 1, fifteen wires were shaken loose from terminal board 2, and small particles of solder and other material caused intermittent short circuits.

IBM has also reported that the necessary documentation applicable to the Saturn V Test Complex, required for contractor-acquired equipment, is behind schedule for delivery from MSFC. This condition has an impact on the scheduled completion date of the Saturn V Test Complex and a day-by-day slippage was reported.

2.6 COMMAND SERVICE MODULE

2.6.1 MILESTONES

Reliability milestones for SC-017 (SA-501), SC-020 (SA-502), SC-102 (SA-503), and SC-103 (SA-504) are presented in Figure 2-32. The first two spacecrafts are Block I configuration. The last two are Block II configuration. Spacecraft assignments are identified in Figure 2-33.

2.6.2 RELIABILITY ENGINEERING

2.6.2.1 Failure Mode and Effects Analysis

NAA/S&ID will prepare a basic FMEA for SC-101 (SA-207). FMEA's for subsequent Block II spacecrafts shall be based upon the SC-101 FMEA but shall take into account pertinent configuration changes. Block II FMEA's are scheduled to be updated by April 1966.

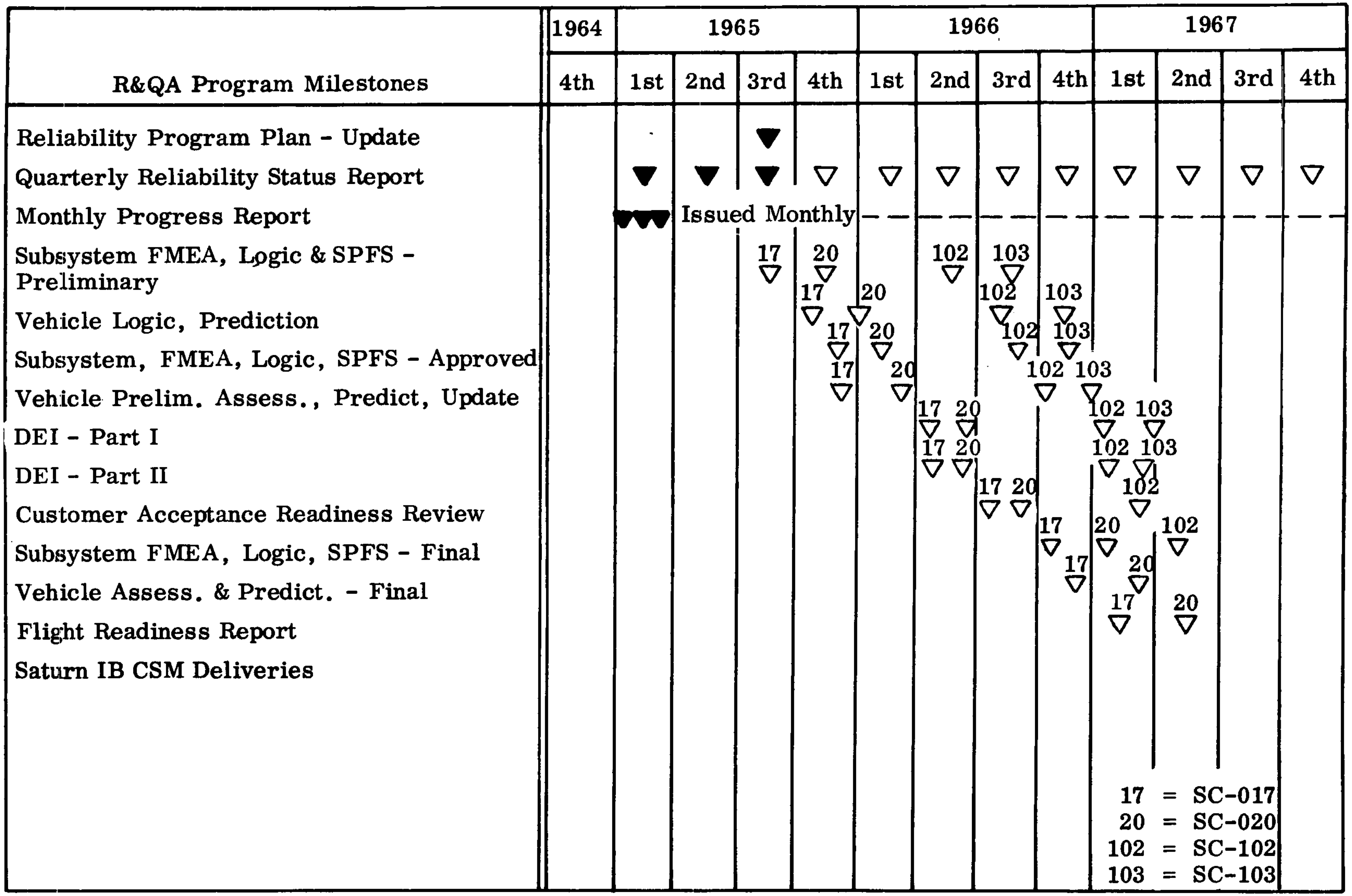
2.6.2.2 Apportionments and Predictions

The Block II CSM reliability apportionments for mission success have been revised by the contractor to reflect a change in the criteria for mission success. The apportionments will be used to:

a. Provide mission success and crew safety reliability goals as inputs to the CSM master End Item Specification (Block II).

b. Perform reliability trade-off studies at the hardware level to determine hardware design goals.

c. Provide subsystem and hardware design goals for procurement specifications.



KEY:

Scheduled: Software ▽ Hardware ○

Completed: Software ▼ Hardware ●

Figure 2-32. Command Service Module Reliability Milestones

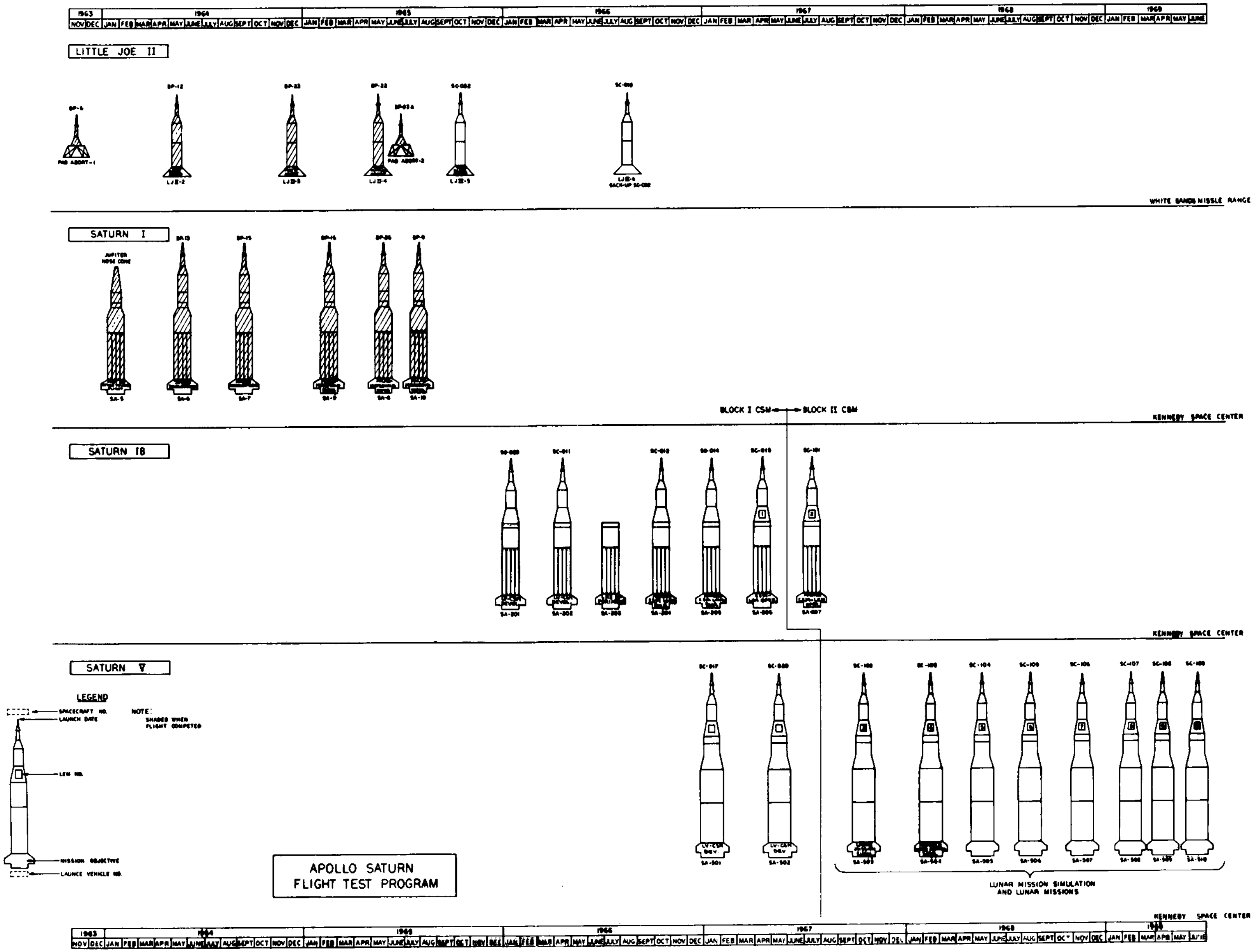


Figure 2-33. Apollo Saturn Flight Test Program

The Block II CSM reliability apportionments reported in the second quarter "Reliability and Quality Assurance" status report were based on the minimum lunar stay time; i.e., mission success was defined as "The successful completion of the mission through minimum lunar stay (2 hours), with no failures that would require an abort, and the subsequent safe return to earth." The contractor is now using a revised definition which defines mission success as "The completion of the mission objectives, i.e., the planned lunar stay through rendezvous and docking, with no failures that would require an abort, and the subsequent safe return of the crew to earth." Mission success apportionments have been revised accordingly to reflect the change.

The previously reported apportionments and predictions for the command/service module are presented in the following table for Block II CSM (Ref. 122):

	Reliability Apportionment	Reliability Prediction
Mission Success	0.9638512	0.9440332
Crew Safety	0.9995131	0.9969842

As a result of the changed mission success cirteria, the reliability prediction data previously reported will also be revised. The tentative reliability prediction schedule for SC-017 and SC-020 is presented in Figure 2-34. Subsystem crew safety apportionments have not been changed. The contractor (NAA) reports the new definition has no effect on the apportionments for crew safety reliability.

Contractor apportionments are currently based upon the 8.28 day "LOR AMPTF Design Reference Mission" issued November 1964. This document is scheduled to be revised by March 1966 with an initial draft available by November 1965. Apportionments will be revised when the new DRM becomes effective.

	Tasks	S/C 017	S/C 020
	1. Mission Objectives and Sequence of Events	-	9/1/65
	2. Operating Time Lines (Mission and Aborts)	-	10/1/65
	3. Subcontractor Reliability Prediction and Failure Rates	-	10/15/65
	4. Vehicle/Subsystem Schematics and "As Design" Configuration	9/1/65	11/1/65
	5. Computer Logic Diagrams Generic and Failure Rate File	9/15/65	11/15/65
	6. Mission Reliability Model (Analytical)	10/1/65	12/1/65
	7. Mission Reliability Model (Computer)	10/15/65	12/15/65
	8. Preliminary Prediction and Vehicle Goal	11/1/65	1/1/66
	9. Preliminary Reliability Prediction Workbook	11/1/65	1/1/66
	10. Preliminary Reliability Data Verification	11/5/65	1/5/66
	11. Update Data (1 through 5)	11/13/65	1/13/66
	12. Update Mission Model	12/1/65	2/1/66
	13. Update Reliability Prediction	12/15/65	2/15/66
	14. Update Reliability Prediction Workbook	2/1/66	4/1/66
	15. DEI Data Verification (Delta from 10)	4/7/66	5/21/66
	16. Final Reliability Data Verification	11/1/66	2/1/67
	17. Final Reliability Prediction	12/1/66	3/1/67
	18. Final Reliability Prediction Workbook	12/1/66	3/1/67
	19. Pre-FRR Reliability Data Verification	12/7/66	3/7/67

Figure 2-34. NAA Tentative Block I CSM Flight Vehicle Reliability Prediction Schedule

2.7 LUNAR EXCURSION MODULE

2.7.1 GENERAL

Contractor reliability estimates for the Manned Lunar Landing mission have been reported (83) as shown in the following:

		This Quarter	Last Quarter
	Reliability Goal	Reliability Estimate	Reliability Estimate
Mission Success	0.984	0.866	0.884
Crew Safety	0.9995	0.9968	0.99717

The difference in the mission success estimate since the last reporting period can be attributed to a further decrease in Reaction Control subsystem (RCS) propellant tank reliability.

Contractor reliability numbers presented in this section are current as of August 1965. Such current information was not available during the time the "Mission Reliability Analysis" (paragraph 2.11 and Appendix C of this report) was developed. For this reason, certain differences in reliability numbers and the conclusions drawn therefrom may be observed between paragraph 2.7 and Appendix C.

A major re-orientation of the LEM test program is being implemented in accordance with LEM development schedule III, dated 16 July 1965. As a part of this re-orientation, several ground test vehicles have been deleted and the subsystem test program redefined. When reliability program milestones become more firm, an updated milestone chart will be added to this section of the report. A tabulation of end-item test hardware, the current objectives, and status of each is presented in Figure 2-35. Flight Test Articles (FTA's) 1 and 2 previously assigned to Apollo-Saturn 501 and 502 Missions have been deleted from the program. Replacement of these vehicles by suitably refurbished LEM Test Article (LTA) 10 and LTA 2, respectively, has been investigated and found to be technically feasible.

End Item	Description of Objectives	Status/Comments
Test Module-2 (TM-2)	Thermal Analysis Verification Vehicle - TM-2 is a full-scale thermal model of the LEM with a command module thermal simulator. TM-2 will be refurbished for use at White Sands Operation (WSO) in mated firing tests with LTA-5D descent stage.	1. Completion of ascent and mated stage thermal vacuum test is prerequisite to thermal vacuum testing with LTA-8.
TM-5	Landing Stability Test Vehicle - A specially lightened descent stage structure with production landing gear. It will be ballasted to LEM inertia with c.g. position but at 1/6 LEM weight.	1. In manufacturing. 2. Completion of landing stability tests is a prerequisite to structural drop tests with LTA-3.
ESI	House Spacecraft No. 1, Phase 1 - ESI is used for the electronic system integration testing and is a facsimile structure with geometrically correct equipment locations. It will insure operational compatibility of electronic subsystems in a LEM-1 system configuration.	1. Structure complete. Harness buildup in progress. 2. Delays encountered in subsystem equipment deliveries.
LTA-1	House Spacecraft No. 1, Phase 2 - LEM configured vehicle used for system integrations, EMC, ACE/LEM compatibility, and support of LEM's.	1. In manufacturing. 2. Initial all-up system integration on LTA-1 rather than ESI due to subsystem delivery delays. 3. Systems integration with ACE is a prerequisite to LEM-1 FEAT.
LTA-2	LEM, Launch vehicle for dynamic tests - A LEM structure consisting of a mass representation of ascent stage and a preproduction descent stage with simulated equipment. Vehicle has correct weight and c.g. for dynamic tests.	1. Currently undergoing vibration tests at MSFC. 2. Under study for refurbishment and flight on Apollo-Saturn 501. 3. Completion of vibration tests with S-IB at MSFC required prior to flight Apollo-Saturn 206.
LTA-3	LEM Structural Demonstration Vehicle. A structurally complete ascent and descent stage. It will be subjected to hydrostatic pressure, vibration, structural drop, static structural, manned drop, and failing load demonstration tests.	1. In manufacturing. 2. Completion of ascent engine hydrostatic pressure tests, the vibration tests at ascent descent and boost environments, and the static structural tests are constraints on Apollo-Saturn 206 flight.
LTA-4	LEM House Spacecraft No. 2 - Complete LEM configuration to be used for ambient electronic support, system vibration tests (mission level), and system drop tests.	1. Deleted from program. 2. Operational system vibration testing at mission levels to be accomplished on LEM-2 and 3.
LTA-5D	Propulsion/Structure Capability Vehicle - A flight-weight structure with descent propulsion subsystem and mass representation of remaining subsystem hardware. Used for mated (with refurbished TM-2) and unmated descent propulsion firings in high altitude development facility at White Sands Operation.	1. In manufacturing. 2. Mated firings with inert TM-2 ascent engine is a constraint on LEM-1 Flight.
LTA-8	Thermal Vacuum Demonstration Vehicle - This vehicle will comprise a complete LEM-1 configuration. It will be tested at MSC to demonstrate manned and unmanned integrated systems performance under thermal-vacuum conditions.	1. Detail parts in fabrication. 2. Apollo-Saturn 206 Mission simulation required prior to Apollo-Saturn 206 Flight.
LTA-10	LEM-SLA Structural Test Vehicle. This is a descent structure without ballast for use at NAA in static structural tests with SLA. Subsequent use for facility verification at ETR.	1. Currently undergoing tests at NAA, Tulsa. 2. Under study for refurbishment and flight on Apollo-Saturn 502.
FTA-1	LEM compatibility with Saturn V launch environment demonstration Apollo-Saturn 501.	1.. Deleted from program.
FTA-2	LEM compatibility with Saturn V launch environment demonstration Apollo-Saturn 501.	1. Deleted from program.

Figure 2-35. LEM Test Hardware

Contractor weight evaluation and trade-off studies are continuing. The over-all LEM weight increase during this reporting period, in excess of 1400 pounds, is attributed to increases in heat shield, ascent and descent engines, and thermal requirements. Specific weight optimization studies are considering the Base Heat Shield, weight trade-offs concerning the alternate nozzle for the descent engine, LTA-8 thermal shielding, and use of a beryllium ladder. The contractor has instituted a Super Weight Improvement Program (SWIP).

2.7.2 RELIABILITY ENGINEERING

2.7.2.1 Design

The RCS propellant tank is a major contributor to LEM unreliability, as noted in paragraph 2.7.1. Reliability estimates for this subsystem have been affected significantly by problems encountered in development of propellant tank bladders.

Studies are being conducted which evaluate incorporation of a failure detection system for the propellant bladders. The high bladder failure rate plus the long lunar stay time make the bladders a most critical component in the LEM reliability models, especially since bladder failures are presently not detectable.

The RCS bladders, a common technology item (GAEC, NAA, and DAC), are presently under development. It is expected that reliability improvement will become evident as development and testing proceed.

The all-battery power generation section of the Electrical Power subsystem is undergoing early development. Current research continues to increase knowledge and confidence in the all-battery system.

During this reporting period, five studies requiring system level analysis, completely or in part, were completed:

a. Probability of LEM requiring CSM rescue.
b. Circuit breaker allotment-power distribution system.
c. Sequential stage separation, elimination of single point failures.

d. Checkout and flight performance requirements.

e. Early pressurization of ascent propulsion system.

2.7.2.2 Failure Mode and Effect Analysis

A few problem areas were brought to light as a result of FMEA's performed on the Descent Propulsion and Explosive Devices subsystems. These problem areas are described briefly in the following paragraphs.

2.7.2.2.1 Descent Propulsion Subsystem

Problems related to the descent Propulsion Subsystem are as follows:

a. Active monitoring of the system is required to indicate to the crew impending failure of the Gaseous Pressurant system. At present, no such detection is available.

b. In general, the instrumentation available for the Descent Propulsion subsystem is inadequate in that instrumentation failures will usually generate conditions that will cause unnecessary abort actions.

2.7.2.2.2 Explosive Devices

There exists potential single failure points associated with explosive devices on LEM which could cause loss of the crew. These are listed as follows:

a. Stage Separation Structural - The contingency of snapping opposing bolts due to tension on landing, causing toppling or deforming of remaining bolts, thus precluding proper separation. At present, no failure detection method is available.

b. Deadfacer - Deadfacing Umbilical Ascent Stage/Descent Stage (AS/DS) - Interruption of electrical connections resulting in loss of descent and ascent engine control. Cannot cut umbilical cable; cannot abort. Loss of crew.

c. Umbilical Cable Cutter - Umbilical cable cut causing total interruption of electrical connections resulting in loss of ascent and descent engine control. Cannot separate AS/DS structure; cannot abort. Loss of crew.

The contractor's reliability organization has identified these problem areas through FMEA's and has provided recommendations to the appropriate in-house activities.

2.7.2.2.3 Communications Subsystem

The previous report noted the Communication subsystem as a problem area through preliminary FMEA evaluation. This system has been the subject of comprehensive system studies leading to several configuration changes and further use of subsystem redundancy techniques. FMEA's are expected to be revised and updated during the next reporting period to reflect the latest subsystem configuration and design.

2.7.2.3 <u>Mathematical Models</u>

Contractor mission success reliability models were developed in detail during this reporting period (for the Environmental Control Subsystem and the Descent Propulsion Ambient Tankage). Previously developed contractor models of the Navigation and Guidance, Stabilization and Control, Reaction Control, Electrical Power, Propulsion, Communication, Instrumentation and Structures subsystems have been updated as required. Studies, to describe the models at lower assembly levels, are continuing on all subsystems. The level of detail described in the models varies with availability of design detail, e.g., from the level of parts such as valves in propulsion subsystems to large assembly levels of the Landing Gear Assembly or Caution and Warning Equipment Assembly which still remain to be clearly defined.

During this period, a detailed crew safety model for the Environmental Control subsystem (ECS) was developed. Previously developed crew safety models have been reviewed and updated, when applicable, on other LEM subsystems. Integration of the detailed models into an over-all LEM System Crew Safety Model will be accomplished during a future reporting period.

2.7.2.4 <u>Apportionment and Prediction</u>

Contractor reported mission success reliability estimates for the over-all LEM during the last three reporting periods are: 0.9093, 0.884, and 0.866 (82) (83). These mission success reliability estimates are listed chronologically, but they should not be considered as indicative of a reliability trend. The numbers, while apparently showing a decrease in reliability, are actually the results of changes in mission profile and modeling ground rules as well as a growth of "in depth" knowledge relating to problem areas affecting mission success. This should be considered a normal occurrence in a development program of this magnitude.

The estimate of 0.9093 was based on the Grumman "Reliability Reference Mission" profile. The later estimates are based upon the Apollo Mission Planning Task Force Design Reference Mission issued in November 1964. Figure 2-36 compares the two profiles. It should be noted that the "lunar stay time" has increased by approximately 30 hours, thereby affecting reliability estimates during and subsequent to that mission phase.

At this point in the LEM development program, it is expected that future reliability estimates will begin to mature toward desired goals as mission objectives and equipment operating profiles are refined, configuration trade-offs become firm, and more experience regarding equipment and subsystem failure rates is gained from the test program.

2.7.3 TEST PROGRAM

2.7.3.1 Summary

As mentioned in 2.7.1 above, extensive changes involving test scheduling and test program orientation have occurred during this reporting period. LEM development schedule III, dated 16 July 1965, is presently being implemented. LEM program scheduling is directed toward completion of ground test constraints six weeks prior to launch dates. Problems in meeting this criterion have been identified for specific test articles and efforts are underway to effect solutions.

2.7.3.2 Ground Support Test

The subsystem test logic has been revised and the Reliability Assurance Test (RAT) program deleted from the Development Verification Test (DVT) program. It is reported, however, that most of the discipline and constraints of the RAT program have been retained in revised DVT planning.

Nominal Phase	Main Phase	Design Reference Mission: Mission Times, Non-Boost Hours	Design Reference Mission: Mission Times, Boost Hours	Design Reference Mission: Total Mission Times	Reliability Reference Mission: Mission Times, Non-Boost Hours	Reliability Reference Mission: Mission Times, Boost Hours	Reliability Reference Mission: Total Mission Times
1	Total Pre-Separation (Includes 10 hours Pre-earth Launch)	77.70	0.37	78.07	90	0.374	90.374
2	LEM Separation to Insertion	0.33	-	0.33	0.478	-	0.478
3	Insertion and Hohmann Transfer Orbit	0.968	0.01	0.978	0.968	0.002	0.970
4	Powered Descent from Pericynthion to Hover	-	0.14	0.14	-	0.133	0.133
5	Hover to Touchdown	-	0.019	0.019	-	0.050	0.050
6	Lunar Stay	34.744	-	34.744	4.0 MS 24.0 CS	-	4.0 MS 24.0 CS
7	Powered Ascent and Injection	-	0.118	0.118	-	0.093	0.093
8	Transfer Coast	0.781	-	0.781	0.70	-	0.70
9	Rendezvous (5 n. mi. to 500 ft.)	0.138	-	0.138	0.167	-	0.167
10	Docking (500 ft. to Contact)	0.25	-	0.250	0.25	-	0.25

Figure 2-36. Design Reference Mission/Reliability Reference Mission (82)

The major portion of the LEM subsystem and component test program is in the Development Feasibility Test and/or the Development Verification Test phase. Highlights of test status are summarized as in the following paragraphs.

2.7.3.2.1 Descent Propulsion

Over 75,000 seconds total hot firing including 10,000 seconds throttling tests and 1,000 seconds at altitude have been accumulated. Development tests at Space Technology Laboratories (STL) are approximately 35 percent complete.

Tests on the descent engine have shown low performance and erosion of ablative thrust chamber. Space Technology Laboratories reports initiation of studies to eliminate these problems.

2.7.3.2.2 Ascent Propulsion

Over 30,000 seconds total hot firing including 8,000 seconds system test and 6,000 seconds at altitude have been accumulated. Development testing is approximately 65 percent complete at Bell Aerosystems.

2.7.3.2.3 Reaction Control

Workhorse engine cluster has completed 250 runs at Marquardt. System firing tests at Marquardt total 1,300 runs, 8,600 seconds and 18,000 starts with system testing about 20 percent complete.

The revised failure rate for the propellant tank bladders, based upon test experience with six-mil single ply bladders, has significantly affected the reliability of the Reaction Control subsystem. Design Verification Testing on the propellant tanks has been rescheduled pending results of bladder development tests.

A summary of major changes between Schedule III and the LEM Development Program Schedule in effect during the last reporting period is as follows:

a. The majority of major end-items associated with the LEM Ground Test Program reflect rescheduled test starts several months later than planned during the last quarter Schedule, 32A. This reorientation results in an over-all test program compression providing little flexibility in the event of schedule slippage.

b. LTA-4, GAEC House Spacecraft No. 2, has been deleted from the program. A primary objective of LTA-4 was to test operative subsystems at mission vibration levels. This testing is now scheduled on LEM's 2 and 3 prior to their shipment to KSC and is considered a flight constraint on LEM-1. Slippage on LEM 2 or 3 could jeopardize test constraints applied to LEM-1.

c. LTA-3 test sequence was changed to allow completion of static structural testing prior to the structural drop test program. This was incorporated to meet the constraint of static structural test completion six weeks prior to Apollo-Saturn 206 Flight.

d. Initial "all-up" system integration and ACE checkout testing will be conducted on LTA-1. This was previously planned to be accomplished with the Electronic System Integration (ESI) test rig. Delays in subsystem deliveries have forced this change and the ESI test logic is being revised for consistency with subsystem hardware availability.

e. The scheduled delivery of LTA-8 to MSC occurs approximately two and a half months prior to LEM-1 launch. This may restrict environmental testing of LTA-8 in support of LEM-1. Although programmed as unmanned, LEM-1 is to be capable of either manned or unmanned flight.

Sea level testing of the propellant system thrust chamber assembly resulted in repeated failures involving the oxidizer valve. The problem is presently being investigated.

2.7.3.2.4 Landing Gear

One sixth scale model landing gear drop tests have been completed.

2.7.3.3 <u>Qualification Test</u>

The subsystem development test logics are in process of review and revision as required to attain scheduled completion of all subsystem qualification programs prior to 15 November 1966.

2.7.4 QUALITY ASSURANCE

2.7.4.1 Manufacturing Performance of Prime Contractor

Figure 2-37 indicates the trend in quality performance of the prime contractor during structural assembly, final assembly, and checkout of LEM. This is shown by the number of observed defects per 1000 direct manufacturing manhours each month at the Grumman site.

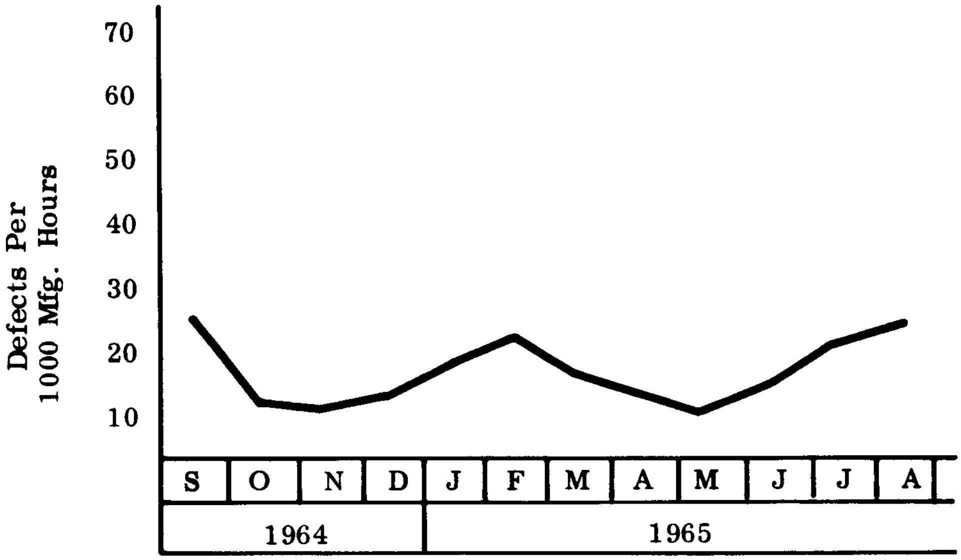


Figure 2-37. LEM Manufacturing Defects at GAEC

2.7.4.2 Failure Reporting and Corrective Action

Failure report printouts from GAEC LEM failure data, from inception of the program through June 1965, have been reviewed for quality problems of the LEM Ascent Engine manufactured by Bell Aerosystems. Following are statistics of note:

Failures Reported (Ascent Engine)	42
Percent of Failures attributed to Quality Problems	48
Failures Reported as critical	10
Failure Reports remaining open	4

Ascent engine significant problem areas are shown in Figure 2-38.

Failure Type	Reported Criticality				Description and Remarks
	Critical	Minor	None	Unspecified	
Injector Faulty Performance	5	9	-	4	This problem accounts for approximately 45 percent of failures. Excessive leakage, improper impingement, manufacturing errors. Eleven failures attributed to quality problems.
Valve Leaks or Improper Operation	-	1	9	3	This problem accounts for approximately 33 percent of failures and is similar to failure type reported as currently most significant in Gemini Propulsion System.
Leakage between Shell and Ablative of Thrust Chamber	2	-	-	-	Design change to be made.
Thrust Chamber Burnout	2	-	-	1	Of two "critical" failures, one was a design problem, one a quality problem.
Connector Failure	1	-	-	-	Design change.

Figure 2-38. Ascent Engine Problem Areas

2.7.4.3 LEM Subcontractor Quality Programs

According to reports by GAEC, prime LEM contractor, only two of the LEM subcontractors appear to be carrying out their quality programs in a completely satisfactory manner. The majority of LEM subcontractors appear to be having quality management problems characterized by disapproval of their quality planning documents, such as quality program plans, sampling plans, and material review procedures; by slowness in submittal of quality documentation and implementation of same; and generally poor implementation of quality procedures and requirements.

The last Grumman Aircraft Engineering Corporation report lists major LEM subcontractor in-house quality performance as shown in Figure 2-39.

Contractor	LEM Equipment	Current Quality Performance Rating
Aerojet General	Propellant Tanks	Good
Allison	Descent Stage Propellant Tank Assembly	Good
American Bosch Arma	Caution and Warning Electronic Assembly, Signal Conditioner Electronic Assembly, and Control Assembly	Fair
AiResearch	Cryogenic Tanks and Gimbal Drive Actuator	Fair
Bell Aerosystems	Ascent Engine	Fair
Hamilton Standard	ECS, GSE and ECS, Inverters	Fair
Honeywell	D'Arsonval and Cross Point Meters	Fair - Poor
Kearfott	Rate Gyro, Helium Temp/Press. Indicator, Propellant Quantity Indicator	Fair
Lear Siegler	Attitude Indicator and Gasta	Fair
Link	Full Mission Simulator	Good
Marquardt	Reaction Control System	Fair
Radiation, Inc.	PCM Timing Equipment	Fair
Radio Corporation of America	G&N Radar, Communications, Attitude and Translation Control Assembly, Descent Engine Control Assembly	Fair
Space Technology Laboratory	Descent Engine, Abort Guidance System	Fair

Figure 2-39. Major LEM Subcontractor In-house Quality Performance

2.8 LAUNCH COMPLEX AND GSE

2.8.1 GENERAL

Apollo-Saturn V Vehicles will be checked out and assembled in the Vehicle Assembly Building (VAB) and launched from Launch Complex 39. Construction of these facilities including the VAB, three Mobile Launchers (ML), a Mobile Service Structure (MSS), and two Crawler/Transporters, continued throughout the quarter. Inspection and tests of facilities and equipment are being conducted by the Corps of Engineers and KSC divisions. Operational tests of Crawler/Transporter No. 1 uncovered roller bearing deficiencies requiring major redesign. Redesign and rework of bearings may affect the Apollo-Saturn 501 Mission schedule.

Reliability analysis effort continued throughout the quarter. The status of this work, with schedules, was presented to the Crew Safety Panel on 21 and 22 September.

No over-all analysis of the checkout and launch operation, aimed at analyzing and assuring the capability to meet mission launch windows, has been undertaken. Various techniques have been studied at each of the MSF Centers but no integrated approach has been initiated.

2.8.2 LAUNCH COMPLEX RELIABILITY ENGINEERING

While reliability analysis efforts on major launch complex hardware have continued throughout the quarter at KSC, no significant results are available for inclusion in this report. FMEA's on Swing Arms and Hold down Arms are scheduled for completion in November 1965. Criticality numbers will be completed in December for these systems.

MSFC has performed Reliability Assurance Evaluation Surveys on suppliers of MSFC provided launch complex equipment. Two contractors, Sanders Associates, and RCA, have been surveyed and results are shown in Figures 2-40 and 2-41. These figures show the degree to which contractors are implementing contractually required elements of NPC 250-1.

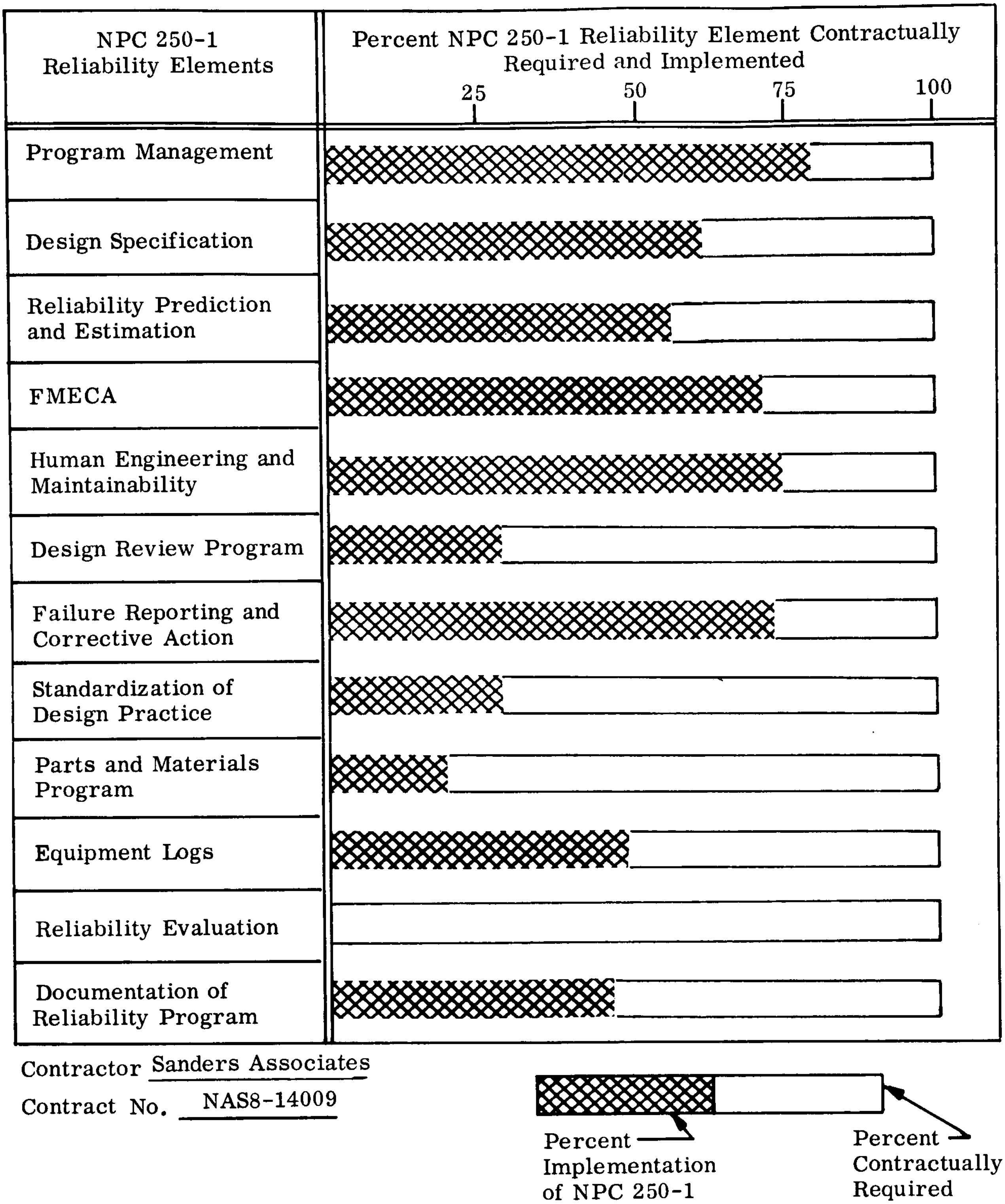
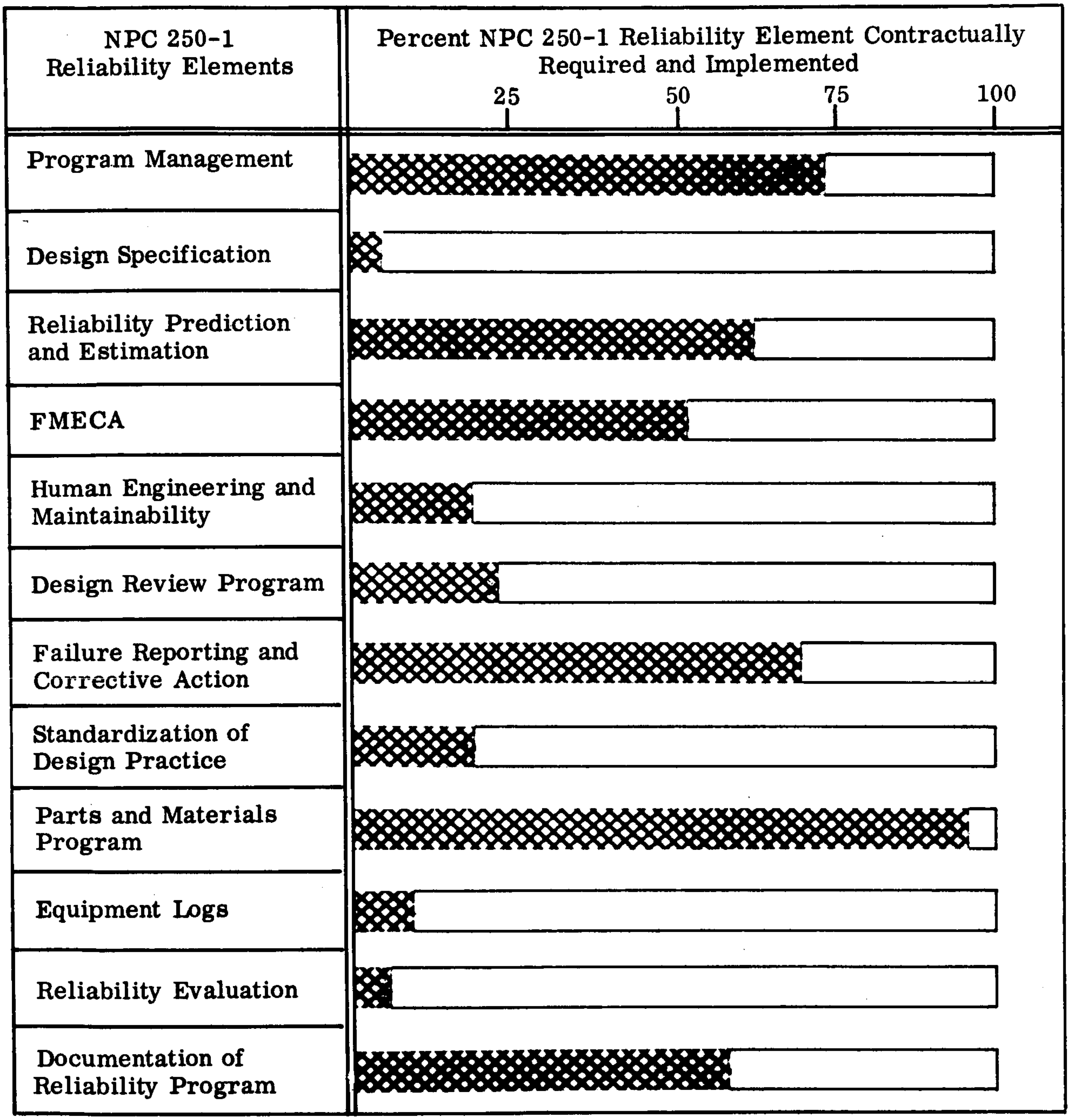


Figure 2-40. Saturn V Operational Display System Reliability Assurance Evaluation Based on NPC 250-1

[redacted]



Contractor Radio Corporation of America

Contract No. NAS8-5423
NAS8-5433
NAS8-13007
NAS8-11582

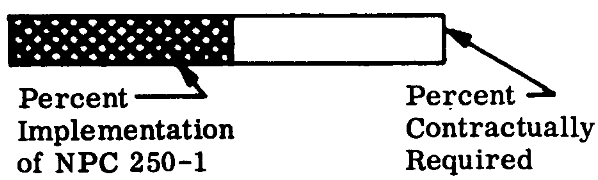


Figure 2-41. Ground Computers, Display and Data Link Systems Reliability Assurance Based on NPC 250-1

[redacted]

2.8.3 TEST PROGRAM

Facility compatibility with the Apollo-Saturn V vehicle will be determined through use of the SA 500-F Facilities Checkout Vehicle. These tests are presently planned for the first quarter of 1966. Operational tests of Crawler/Transporter No. 1 revealed deficiencies in roller bearing assemblies. The problem is caused by bearing loading in C/T turning operations. Other design problems have been reported in the hydraulic leveling system and the braking system of the Crawler/Transporter.

Redesign and rework of the bearing assemblies have been estimated to require four to six months. Any time in excess of four months will affect erection schedule of the SA 500-F vehicle and, consequently, the Apollo-Saturn 501 Mission schedule.

SECTION 3: APOLLO RELIABILITY AND QUALITY ASSURANCE PROGRAM MANAGEMENT

3.1 GENERAL

This section presents the status of NASA reliability and quality activities necessary to establish the broad management base required to plan, implement, and control the Apollo Reliability and Quality Assurance Program. The information in this report is a summary of the activities at the Apollo R&QA Program Office and Manned Space Flight (MSF) Centers.

3.2 PROGRAM PLANNING

Apollo Reliability and Quality Assurance Offices in the Apollo Program Office and at the MSF Centers have prepared or scheduled Reliability and Quality Assurance Program Plans as shown in Figure 3-1.

Plan Title	Activity
Apollo Reliability and Quality Assurance Program Plan	Plan approved and issued August 1965.
MSFC Saturn Reliability and Quality Assurance Program Plan	Draft issued May 1965 has been cancelled. Drafts are being prepared for Saturn IB and Saturn V Reliability and Quality Assurance Program Plans.
Apollo Spacecraft Program Office Reliability Program Plan	Approved and issued August 1964.
Apollo Spacecraft Program Office Reliability Requirements Manual	Issued manual was revised and updated in August 1965.
Apollo Spacecraft Program Office Quality Program Plan	Approved and issued February 1965.
Apollo Spacecraft Program Office Quality Requirements Manual	Draft issued March 1965. Scheduled for completion September 1965.
KSC Apollo Reliability and Quality Assurance Plan	Approved and issued December 1964. Revision 1 scheduled for 4th Quarter 1965.

Figure 3-1. Program Planning Summary

3.3 MANNED SPACE FLIGHT CENTER STATUS REPORTING

Program visibility of reliability and quality progress is attained by means of evaluation and measurement of MSF Center Reliability and Quality Assurance Status Reports.

3.3.1 MANNED SPACECRAFT CENTER (MSC)

MSC/ASPO issued the first Spacecraft Reliability and Quality Assurance Quarterly Status Report dated 15 September 1965. The report presents status of reliability and quality activities of the Apollo Spacecraft Program, highlighting both the management and hardware aspects of the program.

3.3.2 KENNEDY SPACE CENTER (KSC) AND MARSHALL SPACE FLIGHT CENTER (MSFC)

No formal reliability and quality assurance quarterly status reports were issued by KSC or MSFC during the current reporting period. However, MSFC is currently developing a sample monthly status report of the quality program for Saturn V. An initial draft of this sample report was released to the Apollo Reliability and Quality Assurance Office for comments in September 1965.

3.4 MANNED SPACE FLIGHT (MSF) CENTER PROGRAM AUDITS

MSF Centers have been performing scheduled audits of prime system contractors and selected subcontractors. Figure 3-2 depicts a summary of prime contractor audits accomplished and scheduled by MSC and MSFC. There are no schedules available from the implementing divisions at KSC, but they are performing reliability and quality audits of facility and Ground Support Equipment (GSE) contractors.

It was reported by MSC that a highly successful quality audit system had been established and 12 audits have been completed to date. Most of the contractors have been extremely cooperative and receptive to the audit team comments and suggestions as evidenced by a high rate of immediate corrective actions. However, there is a general lack of timely corrective action by contractors when there is disagreement with NASA over the problems uncovered during the audits. Also, corrective action lacks timeliness when early corrective action is not possible (i.e., those involving changes in facilities), thereby, reducing the effectiveness of the contractor's quality program. Management followup has been initiated to help overcome this problem.

Space System	1965					
	J	A	S	O	N	D
S-IB Stage			Q▼			
S-IC Stage		Q▼				
S-II Stage	Q▼					
S-IVB Stage	●					
F-1 Engine						
H-1 Engine						
J-2 Engine						
Instrument Unit		Q▼ 2		Q ▽ 1		Q ▽ 3
Lunar Excursion Module			R▽			Q▽
Guidance and Navigation (ACED)	R▼	Q ▼				
Guidance and Navigation (MIT)						
Command and Service Module				Q ▽ R		
Space Suit				R▽		

Symbols:

▽ - Scheduled Completion Date
▼ - Actual Completion Date
R - Reliability Audit
Q - Quality Audit
● - Government Agency Audit

1 - Audit Owego Facility
2 - Audit Teterboro Facility
3 - Audit Huntsville Facility

Figure 3-2. Summary of MSF Center Reliability and Quality Audits of Prime Contractors

Results of the initial 12 audits have indicated that the general level of contractor and subcontractor quality program effectiveness is considerably less than required for the Apollo Spacecraft Program.

The Saturn IB and Saturn V Project Offices at MSFC are conducting reliability evaluations of prime system contractors to determine the actual implementation of NPC 250-1 as a contractual requirement and to measure the extent to which requirements are being quantitatively implemented.

3.5 TECHNICAL IMPLEMENTATION

Program-wide coordination of selected reliability and quality assurance activities is being accomplished by teamwork of the Reliability and Quality Assurance Offices at the MSF Centers and the Apollo Reliability and Quality Assurance Office. This coordination has been directed toward the following areas where integrated effort will provide maximum program benefit.

3.5.1 SYSTEMS NONPERFORMANCE ANALYSIS

During the past quarter, increased attention has been directed toward failure summary reporting and trend analysis. Significant progress has been made in this activity at both the program and project levels.

On 20 July the first Apollo program-wide presentation of failure summary data was presented at the MSF Program Review. This presentation, while satisfactory for the initial effort, lacked the data content and refinement required for acceptable presentation on a continuing basis. The following two major problem areas were recognized: (1) Additional coordination was necessary with MSF Center Program Offices in order to clarify the program level need for, and the content of, their failure summary inputs. (2) Minor alterations and additions to the MSF Center Program Office failure reporting systems were necessary in order to make them responsive to these failure summary requirements.

An interim requirement instruction was prepared and distributed by the Apollo Reliability and Quality Assurance Office on 20 August. This instruction established categories of failure summary data required, provided a suggested format for data accumulation, established a reporting schedule, and included definitions of terms. Coordination of this instruction between the Apollo Reliability and Quality Assurance Office and MSF Centers resulted in a mutual understanding of requirements and problems.

At the MSF Program Review presentation, 21 September, the large number of unresolved failures was stressed; it was agreed that the Apollo Reliability and Quality Assurance Office would coordinate with the MSF Centers to solve the problem.

MSF Centers, by continuing the planned program of development, have made their failure reporting systems more responsive to Apollo Reliability and Quality Assurance Office requirements. Additional activities currently underway at the centers will go even further in improving their capability to provide program failure data to the Apollo Program Office as well as to their own operations.

During this period, MSFC initiated negotiations with prime contractors to contractually cover failure reporting. A contract change was negotiated with Douglas Aircraft Company, and implementation of the agreement is underway. Negotiations are proceeding with Boeing Company, Chrysler Corporation, and North American Aviation; they are expected to be finalized in the near future.

The Saturn V Program Office is instituting evaluation and reporting on reliability and quality from both hardware and system standpoints. This evaluation, performed monthly, will be utilized primarily for Saturn V management visibility.

The KSC failure reporting system is retrieval-oriented, and it can meet Apollo Reliability and Quality Assurance Office requirements with their generalized computer programs.

3.5.2 SINGLE POINT FAILURE ANALYSIS

Each Directorate in the Apollo Program Office has prepared an action plan based upon assigned responsibilities which are as follows:

a. Program Control - Logistics (Propellants and Transportation).
b. Test - Manufacturing and ground test facility.

c. Reliability and Quality - Space vehicle and associated GSE, launch complex and associated GSE.
d. Flight Operations - The operational support and recovery system.

The Apollo Reliability and Quality Assurance Program Office has coordinated all the action plans and prepared an Apollo Program Directive for distribution.

KSC is performing Failure Mode and Effects Analyses (FMEA's) on all launch support equipment over which they have design cognizance. The FMEA's are used to identify single point failures which could cause loss of life, vehicle loss, launch scrub, or launch delay. KSC program management completed (September 1965) a series of meetings to review all single point failures on the Saturn IB program that could cause loss of life or vehicle. This review included an evaluation of proposed redesign or design modification to design out Priority I items. It is planned to broaden the scope of this review to include Priority II and III items for Saturn IB and, ultimately, Priority I, II, and III for Saturn V. KSC presented the results of the Saturn IB FMEA and criticality number determination to the Crew Safety Panel on 21 and 22 September. The holddown arms and swing arms were reviewed in detail. Priority I is broken into two categories:

a. Safety Systems - Systems which cannot actually cause loss of the vehicle or loss of life, however, their failure to function when a hazardous condition exists could allow the condition to continue, resulting in possible vehicle loss or endangering crew safety.
b. In-Line Systems - Systems in which failure can actually cause a hazardous condition.

3.5.3 TRAINING

The Apollo Reliability and Quality Assurance Office and NASA training offices at each of the MSF Centers continue to provide support to personnel assigned to the Apollo Program. Support has taken the form of a coordinating action in assisting Apollo Program contractors to establish and maintain effective training programs and in making reliability and quality assurance courses and facilities available to NASA Apollo Program personnel.

The following compilation, Figure 3-3, shows total NASA personnel enrollment in available reliability and quality assurance training program for fiscal year 1965.

Course Title	Course Hours	NASA Participants		
		MSC	MSFC	KSC
NASA				
Quality Surveyors' Seminar	40	11	65	7
Reliability Surveyors' Seminar	40	1	34	15
NASA Quality Requirements and NASA Plant Representative	80	10	70	16
Standards and Calibration Laboratory	40	1		
Reliable Electrical Connections (Hand Soldering)	80	4	27	45
Wave Soldering	40		6	2
Crimping	40	2	5	
Module Welding	80	2	8	2
Automatic Systems Checkout Orientation	80	8	23	4
Standard Acceptance Test or Launch Language	40	8	23	1
RCA-110A, Computer Programming	80		16	1
Digital Events Evaluator	80		11	
RCA-110A, Computer Maintenance	200		8	
Optical Alignment (Basic)	80		40	3
Optical Alignment (Advanced)	80		8	2
Cleaning Control and Fluid Analysis	2		2	
Air Force Logistic Command - Wright Patterson AFB				
Management of Quality Control	80			1
Army Management Engineering Training Agency				
Statistical Quality Control	80			1
Inspection Planning	40			2
Seminar for Quality Managers	40			3
University of Connecticut				
4th Quality Control Management Institute	40		2	
5th Annual Statistical Quality Control Institute	80		1	
Purdue University				
Statistical Methods and Advanced Quality Control	80		1	
Massachusetts Institute of Technology				
Probabilistic Systems Analysis	80		1	
University of California				
Systems Approach to Reliability	40		2	
Management Seminar in Reliability and Engineering Operations	80		1	
Non-destructive Testing Principles and Laboratory Practices	80		1	
Mechanical Metrology and Measurement Standards	80		1	
Chrysler Corporation				
Human Factors and Maintainability	80			3
Sheffield Corporation				
Industrial Metrology	40			1
American Welding Society				
Testing and Inspection of Welds	16			1
George Washington University				
Maintainability Engineering and Management	40			1
University of Arizona				
Reliability Engineering and Management	40		2	
American Management Association				
Quality Control Course	40		1	
		47	359	111

Figure 3-3. NASA Apollo Reliability and Quality Training Program Status

In addition to established reliability and quality assurance courses, the programs listed in Figure 3-4 are presently under development by MSF Centers.

Title	Course Hours	Description	Course Development Responsibility*
High Pressure Systems RQA/M9	80	Methods of fabrication, assembly inspection, and testing of reliable high pressure fluid and gas systems.	Code: R-QUAL-OT
NASA Requirements in Metrology RQA/G5	80	Techniques and methods of evaluating calibration capabilities of supplier field installations.	Code: R-QUAL-T
Reliability Training (General)	30	Reliability measurement, uses, and limitations of reliability.	Code: KR
Nondestructive Testing RQA/M1 and RQA/M2	80	Basic requirements of five techniques of nondestructive testing; NASA specification requirements and their interpretation, contractor evaluation of nondestructive testing techniques.	Code: R-QUAL-OT
Electromagnetic Interference	80	Comparison, interpretation and application of MSFC-279 and MIL 6181B.	Code: R-QUAL-OT
Electromagnetic Compatibility	40	EMI/EMC consideration at management and technical levels. Factors controlling project specification, design considerations and cost factors related to EMC are discussed.	Code: MAR
<u>Reliability Evaluation Courses</u>			Code: KR
Test and Checkout Surveillance Management Orientation	6-12	These short courses are under development to indoctrinate new reliability personnel to make reliability evaluations and to orient project managers in the benefits to be obtained from reliability evaluation procedures.	
Test and Checkout Surveillance Technical Course	30-40		
Reliability Program Evaluation Management Orientation	6-12		
Reliability Program Evaluation for Reliability Assurance Personnel	30-40		

*Note: Administration and coordination of Training Program between the respective MSF Centers is provided by Code BPT, NASA Headquarters, Washington, D.C.

Figure 3-4. Reliability and Quality Assurance Courses Under Development

3.5.4 MOTIVATION

In the area of reliability and quality motivation, the Manned Flight Awareness Program initiated by MSFC continues to expand its activities and influence. The film, "The Essential Component," produced for the program has found acceptance, and it is being used extensively in Apollo motivational programs and for orientation of new personnel.

Motivation programs currently reported as being implemented by Apollo contractors include those shown in Figure 3-5.

Apollo Contractors	Motivation Program
Spacecraft	
North American Aviation, S&ID	PRIDE - Professional Responsibility In Daily Effort
Grumman Aircraft Engineering Corp	STERLING
AC Electronics Division	PRIDE - Professional Responsibility In Daily Effort
General Electric Company	ZD - Zero Defects
Launch Vehicle	
The Boeing Company	ZD - Zero Defects
Chrysler Corporation	CARE - Chrysler Always Requires Excellence
North American Aviation, S&ID and Rocketdyne Division	PRIDE - Professional Responsibility In Daily Effort
Douglas Aircraft Company	VIP - Value In Performance
Electronics Communications, Inc.	MFA - Manned Flight Awareness
Bendix	MFA - Manned Flight Awareness
International Business Machines Corp	MFA - Manned Flight Awareness

Figure 3-5. Apollo Motivation Programs

MSFC, commencing this quarter, has prepared a traveling van exhibit to visit Saturn contractors and subcontractors. Those who have received the presentation during this quarter are shown in Figure 3-6. It is scheduled for Southeastern United States the last quarter of 1965 and the West Coast the first quarter of 1966.

Date of Visit	Company Visited
30 June to 4 July 1965	Bendix Corporation, Teterboro, N.J.
6-8 July	ACF Electronics, Paramus, N.J.
9-14 July	IBM, Owego, N.Y.
15-17 July	Maratta Valve Corporation, Boontown, N.J.
20-23 July	Rome Cable Division of ALCO, Rome, N.Y.
26-27 July	Bulova Watch Company, Long Beach, N.Y.
28-29 July	AVCO Corporation, Lowell, Mass.
2-3 August	ITT, Clinton, Mass.
5-8 August	MIT/Instrument Laboratory, Cambridge, Mass.
9-10 August	Nortronics Division, Norwood, Mass.
16-18 August	NASA, Washington, D.C.
23-24 August	Sperry Farragut Company, Bristol, Tenn.
30-31 August	AVCO Corporation, Nashville, Tenn.
September	Return to Huntsville, Alabama, for internal use, local contractors, and rework.

Figure 3-6. Saturn-Apollo Manned Flight Awareness Presentation Schedule

3.5.5 PARTS AND MATERIALS PROGRAM

An Apollo Parts and Materials Management Panel has been established to coordinate MSF Center parts and materials activities. Members of the panel are an Apollo Reliability and Quality Assurance Office chairman and MSF Center representatives. The Panel will foster mutual cooperation and exchange of information by illuminating center activities and needs. Panel meetings were held to draft the panel charter and discuss formulation of the Apollo Parts Information Center (APIC).

Plans for APIC include the following three developmental phases:

a. Utilization of existing PRINCE capabilities and adjustments to initiate APIC.
b. Refinements to APIC to assure agreement with the Apollo Reliability and Quality Assurance Program Plan.
c. Continuing APIC program refinement.

The MSC Parts Working Group held meetings with prime system contractors and discussed specific part failures and the document titled Parts Qualification Ground Rules. One of the purposes of this document is to establish a framework for better uniformity of parts qualification data.

MSC has encountered a problem in obtaining sufficient parts lists from North American Aviation and its subcontractors for publication of a parts list by 15 October 1965. A concerted effort is being carried on to obtain the required information.

3.5.6 CREW RELIABILITY STUDIES

The Apollo Reliability and Quality Assurance Office is continuing support of OMSF Contract NASw-1187 with the Martin Company, Baltimore, Maryland, for studies on crew performance. Results are available from lunar landing mission simulations from 24 June to 2 July 1965 (Mission I) and from 6 August to 13 August 1965 (Mission II). The third mission simulation began 17 September 1965. Each of the first two missions progressed well, and the performance of crews was quite high.

Data reduction will be performed as a MSC sponsored work effort. It is planned to convert data into such factors as the following:

a. Percent variability in performance from pilot to pilot and from the theoretical optimum.
b. Instrument panel layout optimization.
c. Nature of errors induced by the crew.

A synopsis of flight performance and preliminary mission data summaries for the first two missions is presented in Figure 3-7.

Flight Performance Summary		
Activity	Mission I	Mission II
1 Flight Control	All measures were within performance criteria for all pilots, all phases, and all parameters.	No instances of performance exceeding criteria value. Two instances of performance equaling criteria value.
2 Guidance and Navigation Sighting Angles	All pilots for all phases were within the ±2° performance criterion.	All sighting errors were within ±2° system tolerance.
3 Switching	Total Switches 6547 Total Switch Deviations 20 Mission Switching Reliability 0.997	Total Switches 6443 Total Switch Deviations 7 Mission Switching Reliability 0.999

Mission Data Summary (Preliminary)					
Task	Contract Goal	Mission I Trials	Data Points Lost	Mission II Trials	Data Points Lost
Switching	6594	6547	47	6443	151
CM Flight Control	98	96	2	98	0
LEM Flight Control	63	46	17	66	0
G&N Switching Angles	80	146	0	143	0
Isometrics	100	77	23	99	1
Malfunction Correction	20	23	0	23	0
Total	6955	6935	89	6872	152
Percentage of total flight data			1.3		2.2

Figure 3-7. Flight Performance and Preliminary Mission Data Summaries

3.5.7 RELIABILITY MANAGEMENT STUDY

The Apollo Reliability and Quality Assurance Office is conducting a study to define existing reliability interfaces and relationships at the program level and the manner in which reliability implementation is accomplished. To date, the study has encompassed the relationship of Apollo reliability policy with Apollo Program and NASA policy.

Conclusions and recommendations from this study suggest the establishment of detailed reliability and quality milestones as a part of the Apollo Reliability and Quality Assurance Program Plan, correlation of the proposed milestones with Manned Space Flight schedules to implement performance evaluations, and improved information handling and interchange among management organizations.

3.5.8 INCENTIVE CONTRACTS

The Office of Manned Space Flight has established an objective of converting all ten major cost-plus-fixed-fee hardware contracts to an incentive basis during 1965, in accordance with the schedule shown in Figure 3-8.

To define OMSF policy and assist MSF Center reliability and quality organizations in contract conversions, the Apollo Reliability and Quality Assurance Office issued a report on 13 September, which defines general requirements to be met by schedule, cost, and performance incentives. Features of the report include the following:

a. Establishment of incentive priorities.
b. Definition of required reliability and quality performance.
c. Selection of key reliability and quality performance milestones based on reliability and quality assurance plans.
d. Establishment of performance criteria to assist MSF Centers during pre-negotiation phase.
e. Establishment of incentive categories; namely, milestone incentives, early indicator incentives, and mission success incentives.

3.5.9 APOLLO PROGRAM RELIABILITY AND QUALITY GUIDELINES

A summary of Apollo Reliability and Quality Assurance standards, procedures, and guidelines being prepared or in process of being coordinated or issued is shown in Figure 3-9.

3.5.10 QUANTITATIVE RELIABILITY ANALYSIS

The plan for Apollo Program Quantitative Reliability Analysis, presented by the Apollo Reliability and Quality Assurance Director at the MSF Program Status Review Meeting in March, has been partially implemented by MSF Centers. For this plan to be effective, each MSF Center and contractor must prepare a reliability model reflecting the

Project	Contractor	Contract Number	1964 Nov	1964 Dec	1965 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LEM	GAEC	NAS9-1100					▼1	▽2	▽3 ▽4	▽5		▽6				
C/SM	NAA	NAS9-150						▼1 ▼2			▽3 ▽4	▽5		▽6		
F-1 R&D	NAA/Rocketdyne	NASW-16					▼1	▼2	▼3 4 5			▼6				
F-1 PROD	NAA/Rocketdyne	NAS8-5604						▼1				▼2	▽3	▽4 5	▽6	
J-2 R&D	NAA/Rocketdyne	NAS8-19							▼1			▽2	▽3 4	▽5	▽6	
J-2 PROD	NAA/Rocketdyne	NAS8-5603	▼1		▼2				▼3 4		▼5	▽6				
S-II	NAA	NAS7-200										▼1		▽2	▽3 4	▽5 6
S-IVB	Douglas Aircraft	NAS7-101					▼1			▼2			▽3 4	▽5	▽6	
S-I-IB	Chrysler Corporation	NAS8-4016								▼1		▽2	▽3	▽4 5	▽6	
S-IC	Boeing	NAS8-5608										▼1		▽2	▽3 4	▽5 6

▽1 Completion of Specification
▽2 Contractor Proposal Due
▽3 Pre-Negotiation to HQ
▽4 Start Negotiations
▽5 Complete Negotiations
▽6 Contract to HQ
▽ Scheduled
▼ Complete

Figure 3-8. Apollo Incentive Conversion Schedule

No.	Title	Activity During this Quarter	Present Status
1	Guideline for Interpretation and Selective Application of NPC 250-1	Coordination draft was reviewed by Apollo Program Office and Centers in August 1965.	Revised guideline draft, incorporating inputs from the August Review Meeting, was completed 30 August.
2	Guideline for the Preparation and Maintenance of Equipment Logs	None	Draft of the guideline is being reviewed by the Centers.
3	Guideline for Establishing Apollo Parts Programs	Comments received from the Centers were reviewed and the February draft of the guideline was rewritten to incorporate these inputs.	The revised draft of the guideline to be completed 30 September 1965.
4	Guideline for Failure Mode and Effects Analyses and Criticality Analysis	The June 1965 draft of this guideline was rewritten incorporating coordination inputs.	The third draft of this guideline completed 1 September 1965.
5	Electromagnetic Compatibility Principles and Practictices	Copies of the manual were reproduced for use in conducting the initial EMC Awareness Course.	Draft copies of the manual are presently available.
6	Identification for Traceability Standard	Preparing coordination drafts of Standard.	Scheduled to be completed 30 September 1965.
7	Review and Disposition of Nonconforming Material on the Apollo Program	Title changed from Policies and Procedures for Review Board Activities. Centers' review comments of draft being incorporated into coordination draft.	Scheduled to be completed 30 September 1965.
8	Quality Audit Handbook	Prepared Preface and Introduction pages.	Included in Handbook, August 1965.
9	Preparation of Contractor's Quality Program Plan	No Activity.	Coordination with Centers complete. Ready for publication.

Figure 3-9. NASA Reliability and Quality Assurance Guidelines

No.	Title	Activity During this Quarter	Present Status
10	Apollo Metrology Requirements Manual	Coordination comments were resolved and incorporated into Manual.	Final draft is awaiting number designation and printing.
11	Directory of Laboratory Locations and Metrology Capabilities	Draft completed July 1965.	Review in process.
12	Preparation of Supplier's Inspection Plan	No Activity.	Coordination with Centers complete. Ready for publication.
13	Index and Format of Certification and Calibration Procedures	Draft completed June 1965.	Review in process.
14	Interlaboratory Comparison Procedure	Report on recommended "Interlaboratory Comparison Procedure" was completed June 1965.	First draft of the Procedure is in preparation.
15	Quality Requirements for Separable Fluid Connectors and Fittings	Investigated Status and probable impact on Apollo.	Final draft to be completed 30 September 1965.
16	Cleanliness Standards and Contamination Control	Issued Certification Procedure for Contamination Control.	Contamination Control Handbook scheduled to be completed December 1965.
17	Process Specification for Radiography	No Activity.	Distributed to Centers for review and comment in May 1965.
18	ASPO Reliability and Quality Assurance Policy for Material Review Board Activities on Apollo Spacecraft Program	Report Completed.	Expected Approval September 1965.

Figure 3-9. NASA Reliability and Quality Assurance Guidelines (Cont.)

level of detail necessary for its own program. At a coordination meeting in May, it had been agreed by MSF Center and contractor personnel that the analysis approach outlined by the Quantitative Analysis Plan could be implemented without serious impact on the contractors.

Major problems previously revealed which still are not resolved include the following:

a. Lagging launch availability analysis.
b. The need for early determination of reliability mission profile.

The development of a compatible family of reliability analysis models within the Apollo Program is dependent upon the utilization of a common mission by contractors and MSF Centers at all levels. MSC and the spacecraft contractors are working to a Design Reference Mission, which needs to be broadened in scope to include more completely the launch vehicle and launch complex.

Organizational and technical requirements have been established at MSC and the system is producing significant outputs. As shown by Figure 3-10, prime contractor models have been reviewed and a level II model is being assembled. Initial contractor reviews have been followed by working sessions to revise and update information for compatible analyses.

System	1965					
	J	A	S	O	N	D
Spacecraft						
204 Configuration	▽	▼				
504 Configuration		▼				
Lunar Excursion Module						
200 Series Configuration	▽	▼				
500 Series Configuration					▽	
Guidance and Navigation						
204 Configuration	▽	▼				
504 Configuration	▽	▼				

▽ Schedules ▼ Actual

Figure 3-10. Reliability Analysis Review Schedule

MSC also has initiated a Project Apollo Spacecraft Reliability Analysis Management Panel with the expressed purpose of coordinating and expediting the timely accomplishment of a complete quantitative reliability analysis of the Apollo Spacecraft and the associated support equipment for each Lunar Landing Mission [Apollo-Saturn 504 (CSM-102 and LEM-4) and subsequent] and designated preparatory missions [Apollo-Saturn 204 (CSM-012) and subsequent] . MSC has major elements of the Apollo-Saturn 504 Spacecraft model in place, but current major acitvity is directed toward the Apollo-Saturn 204 Mission.

Panel meetings have been held in June, July, and September, and future meetings are scheduled bimonthly hereafter. At the first meeting held in June, the panel reviewed the charter, and each contractor appointed a permanent representative to the management panel. The panel, at subsequent meetings, has established failure criteria for Spacecraft equipment and discussed in detail the procedures for Apollo Spacecraft Quantitative Reliability Assessment.

The MSC Management Panel has also conducted an Electronic Data Processing Interface Study which shows a need for a common equipment code. None of the Spacecraft model ingredients at Grumman Aircraft Engineering Corporation and North American Aviation are available on magnetic tape in a form which would be suitable for processing at the center. The Study results also indicate that tape transmittals between MSC and the contractors cannot be expected until 1966, and computer compatibility problems require further study.

Meetings have been held at MSFC during September to discuss the level II launch vehicle model. As a result of these meetings, level II and level III model reviews will be scheduled.

3.5.11 SATURN POST-LAUNCH FAILURE SUMMARY REPORTS

Beginning with SA-5 and continuing through SA-10, the KSC Reliability and Quality Assurance Office has published failure summary reports within 30 to 60 days after each Saturn launch. The latest documents published in this series are <u>Failure Reporting Summary, SA-8 Pre-Launch Test and Checkout at KSC</u>, dated 7 July 1965, and <u>Failure Reporting Summary, SA-10 Pre-Launch Test and Checkout at KSC</u>, dated 10 September 1965.

These documents contain information received on failure reports, which consist of Unsatisfactory Condition Reports, written by KSC organizations and Chrysler Corporation Space Division; Failure and Rejection Reports, written by Douglas Aircraft Company; and Parts Discrepancy and Disposition Reports, written by Fairchild-Hiller. The information contained in these failure reports is analyzed and the following data is presented:

a. Charts, tables, and narrative information concerning failure reports and problems encountered during vehicle launch operations.
b. The number of reports written against vehicle, stage, and ground support equipment for each launch.
c. Reports written on equipment, the failure of which can cause loss of vehicle, loss of life, launch scrub, or launch delay with associated analysis findings.
d. Number of failure reports written during each calendar week and the operation in process when the failure or problem was detected.
e. The most frequently reported generic items, such as amplifiers, cable assemblies and valves, and details including information on failures of identical part numbers during previous Saturn vehicle operations.
f. Failure of time-and-cycle critical components at KSC.
g. Failure reports written on the current vehicle and associated ground support equipment functional systems.
h. Significant checkout problems, countdown demonstration problems, and countdown problems occurring during launch operations on the current vehicle as well as final resolution of countdown problems occurring during terminal countdown of the previous Saturn vehicle.
i. Failure reports written on tracking, telemetry, and ground measurement instrumentation equipment used to support Saturn launch operations.

These failure summary reports receive wide distribution within KSC and MSFC, and copies are forwarded to MSC, NASA Headquarters, Saturn stage contractors, and NASA Center launch teams located at Cape Kennedy, such as Goddard Space Flight Center and Jet Propulsion Laboratory.

APPENDIX A
REFERENCE DOCUMENTS

1. NASA/OMSF, "Manned Space Flight Schedules (U)," August 1965, CONFIDENTIAL.
2. NASA/OMSF, RA-018-001-1, "Apollo R&QA Program Quarterly Status Report (U)," 9 July 1965, CONFIDENTIAL.
3. NASA/OMSF, Level III Reliability Math Model Review at NAA/S&ID on 10-12 August 1965; Report on 14 September 1965.
4. NASA/OMSF, MAP-1 Weekly Highlight Reports, 1 July 1965 through 9 September 1965.
5. NASA/OMSF, "Proceedings, Apollo Mission Reliability Analysis Guidelines Conference," Apollo R&QA Office, 11-12 May 1965.
6. NASA/OMSF, NHB 5300.1 "Apollo Reliability And Quality Assurance Program Plan (U)," 1965.
7. NASA/OMSF, "Apollo Program Flight Mission Directive for Apollo-Saturn 202 Mission."
8. NASA/OMSF, M-D MA 2240.061, "Apollo Program Flight Mission Directive for Apollo-Saturn 201 Mission," 13 May 1965.
9. NASA/OMSF, SE 005-001-1, "Apollo Program Specification (U)," May 1965, CONFIDENTIAL.
10. NASA/OMSF, Apollo R&QA Office, Internal Memorandum, Subject: Apollo Incentive Conversion Schedule, 10 September 1965.
11. NASA/OMSF, "Manned Space Flight Schedules (U)," September 1965, CONFIDENTIAL.
12. NASA/MSFC, "Saturn V Program Development Plan (U)," October 1964, CONFIDENTIAL.
13. NASA/MSFC, "Launch Vehicle Digital Computer & Data Adapter," Contract NAS8-11561, IBM.
14. NASA/MSFC, "Fabrication of Launch Vehicle Digital Computers, Data Adapters & Associated Hardware for Saturn IB/V," Contract NAS8-11562, IBM, September 1964.
15. NASA/MSFC, "ST-124M Stabilization Platform System & Associated Equipment Design & Documentation," Contract NAS8-5399, Bendix, August 1963.
16. NASA/MSFC, "ST-124M Stabilization Platform System & Associated Equipment Design & Documentation," Contract NAS8-13005, September 1962.
17. NASA/MSFC, "Flight Mission Directive Apollo-Saturn 201 Mission," March 1965.

18. NASA/MSFC, "Flight Mission Directive Apollo-Saturn 202 Mission," Draft.

19. NASA/MSFC, Dwg. 10M30152, "Saturn IB/SA-201 Flight Sequence," 23 March 1965.

20. NASA/MSFC, "Saturn I/IB Program Meeting," MSFC/MAR, 23 April 1965.

21. NASA/MSFC, "Reliability Assurance Evaluation Program of Contract NAS8-4016, 9 September 1965.

22. NASA/MSFC, "Reliability Assurance Evaluation Program of Contract NAS7-101, S-IVB, 9 September 1965.

23. NASA/MSFC, "Reliability Assurance Evaluation Program of Contract NAS8-19, J-2 Engine," 9 August 1965.

24. NASA/MSFC, "Reliability Assurance Evaluation Program of Contracts NAS8-14000, -11561, -11562, -5399," 9 September 1965.

25. NASA/MSFC, "Instrument Unit Reliability Program Status Report #4," (ARINC) July 1965.

26. NASA/MSFC, Minutes of the Saturn IB Design Review #5, 1 July 1965.

27. NASA/MSFC/MSC, 65-FMP-1, Apollo Trajectory Document "Apollo Mission 202 Joint Reference Trajectory (U)," 12 April 1965, CONFIDENTIAL.

28. NASA/MSFC, "S-IVB Reliability Program Progress Report," August 1965.

29. NASA/MSFC, "Saturn V Reliability Analysis Model, SA 501," 7 September 1965.

30. NASA/MSFC, "Michoud Q&R Status Report," March and June 1965.

31. NASA/MSFC, "Summary of Discrepencies on F-1 Engines at MSFC Incoming Inspection."

32. NASA/MSC, "Apollo Spacecraft Program Office Reliability and Quality Assurance Quarterly Status Third Quarter - 1965", 15 September 1965.

33. NASA/MSC, "Project Apollo, Abstract of Proceedings, First Spacecraft Reliability Analysis Management Panel Meeting," 2-3 June 1965.

34. NASA/MSC, "Project Apollo, Abstract of Proceedings, Second Spacecraft Reliability Analysis Management Panel Meeting," 13-14 July 1965.

35. NASA/MSC, NASA Program Apollo Working Paper No. 1153, "Program Apollo Flight Mission Directive for Mission A-201 (U)," (AFRM 009), CONFIDENTIAL K.L Turner, Airframe 009 Spacecraft Manager, 14 December 1964.

36. NASA/MSC, "Program Apollo Flight Mission Directive for Mission A-201 (U)," CONFIDENTIAL.

37. NASA/MSC, "ASPO Reliability and Quality Assurance Quarterly Status," 15 September 1965.

38. NASA/MSC, "Minutes of NASA/North American Monthly Status Review," 15 September 1965.

39. NASA/KSC, K-1B-011, "Apollo/Saturn IB Launch Complex 34 Modification Plan," Books 1 and 2, Apollo Saturn I/IB Test and Systems Engineering Office, 19 March 1965.

40. NASA/KSC, K-IB-014, "Apollo/Saturn IB Launch Complex 34 Facility Checkout Plan," Apollo Saturn I/IB Test and Systems Engineering Office, 15 May 1965.

41. NASA/KSC, F6-OP-SC-009, "Operational Test Plan, " S/C 009, Florida Facility, 6 January 1965.

42. NASA/KSC, "KSC Operations Plan, Apollo/Saturn V Program"

43. NASA/KSC, "AS-201 Daily Status Report," 14 August through 22 September 1965.

44. ACED, "Reliability and Quality Assurance Guidance & Navigation Program Review," May 1965.

45. ACED, "Apollo Guidance & Navigation Quarterly Quality Status Report," June 1965.

46. Bendix Corporation, ST-124-M, "Monthly Quality Status Report," June and July 1965.

47. Boeing Company, "Saturn V Quarterly Technical Report Review," System Engineering & Integration Support, Fourth Quarter Fiscal Year 1965.

48. Boeing Company, D5-11200, "Model Specification for Rev. B, Saturn S-IC Stage" 1 June 1964.

49. Boeing Company, D5-11954-1, "Saturn S-IC Stage Reliability Analysis Record," 1 April 1965.

50. Boeing Company, D5-11954, "Saturn S-IC Stage Rev A, Reliability Assessment and Prediction Program," 18 May 1965.

51. Boeing Company, D5-11935-8, "Monthly Technical Progress Report," 2-29 August 1963.

52. Boeing Company, D5-12572-1, "S-IC-501 System Design Rev. C, Analysis" (Propulsion-Mechanical) (R), 21 January 1964.

53. Boeing Company, D5-11704, "Saturn S-IC Reliability Data Document" (Contains AVCO Generic Failure Rate Data), 11 August 1963.

54. Boeing Company, D5-11954, "Saturn S-IC Stage Reliability Assessment and Prediction Program," 13 July 1964.

55. Boeing Company, "Annual Progress Report," Saturn S-IC, FY 1965.

56. Boeing Company, D5-11954, "Saturn S-IC Stage Reliability Assessment and Prediction Program," 12 August 1965.

57. Boeing Company, "Saturn S-IC Quarterly Technical Progress Report and Program Review," 28 July 1965.

58. Boeing Company, "Saturn S-IC Contractor Qualification Program," June 1965.

59. Boeing Company, D5-11372, "Parts Selector and Control Program Plan" - Saturn S-IC, 28 May 1965.

60. Boeing Company, D5-11013, "Reliability Program Plan," 19 May 1965.

61. Boeing Company, "Saturn S-IC Stage Program Schedule," 15 January 1965.

62. Boeing Company, "Reliability Critical Parts Status," 11 May 1965.

63. Boeing Company, D5-12741, "Saturn S-IC Qualification Status List," 4 May 1965.

64. Boeing Company, D5-11593, "Launch Systems Branch Record System," 21 July 1965.

65. Boeing Company, "Monthly Quality Status Report," July 1965.

66. Chrysler, SDES 65-450, "Systems Design Analysis, Saturn S-IB-1 Stage," 9 August 1965.

67. Chrysler, SDES-65-409, "Systems Design Analysis, Saturn S-IB-2 Stage," 20 April 1965.

68. Chrysler, REL-10, "Reliability Program Plan for Saturn S-I and S-IB Stages," 22 April 1964.

69. Chrysler, TN-RE-65-28, "S-IB-1 Reliability Model, Summary of 10,000 Simulated S-IB-1 Flights," 2 April 1965.

70. Chrysler, "S-I/IB Monthly Quality Status Report," March and June 1965.

71. Chrysler, "S-I/IB Quarterly Qualification Status Lists," June 1965.

72. Chrysler, "Twelfth Quarterly Review, Saturn S-IB Stage and Saturn I Vehicle Program," 30 June 1965.

73. DAC, "Reliability Math Model, Saturn IB/S-IVB-201," January 1965.

74. DAC, SM46667, "Reliability Math Model, Saturn IB/S-IVB-202," May 1965.

75. DAC, A3-857,"S-IVB PERT Bi-weekly Report with Analysis" 6 August 1965.

76. DAC, SM-46667, "Reliability Math Model, SaturnIB/S-IVB-201 Stage," Supplement 1, March 1965.

77. DAC, SM-44748, "Reliability Math Model, Saturn V/S-IVB Stage," Supplement 15 June 1964.

78. DAC, "S-IVB Stage Reliability Program," PSAC, March 1965.

79. DAC, SM 46644, "Intermediate Reliability Program Plan, Saturn S-IVB," June 1964.

80. DAC, "Saturn S-IVB Schedules," 3 September 1965.

81. DAC, "S-IVB Monthly Quality Status Report." June 1965.

82. GAEC, LPR-550-8, "Quarterly Reliability Status Report," 1 May 1965.

83. GAEC, LPR-550-9, "Quarterly Reliability Status Report," 1 August 1965.

84. GAEC, Contract NAS9-1100, "LEM Development Program Requirements, Support of LLR-13-8," 4 August 1965.

85. GAEC, LPR-10-46, "Monthly Progress Report No. 30," 10 August 1965.

86. GAEC, GAEC Handout, "LEM Program Review," 6 July 1965.

87. GAEC, LPR-50-20, "Monthly Quality Status Report for LEM No. 9," 10 October 1964.

88. GAEC, LPR-50-42, "Monthly Quality Status Report for LEM No. 17," 10 June 1965.

89. GAEC, LPR-50-33, "Monthly Quality Status Report for LEM No. 13," 10 February 1965.

90. GAEC, "Monthly Quality Status Report for LEM," July and August 1965.

91. GE/ASD. RAU4, "Electrical Support Equipment Failure Effect and Criticality Analysis of the Saturn IB, S-IB Stage," Parts I and II, March 1965.

92. GE/ASD, RAU5, "Electrical Support Equipment Failure Effect and Criticality Analysis of the Saturn IB, S-IVB Stage," Parts I and II, June 1965.

93. GE/ASD, RAU6, "Electrical Support Equipment Failure Effect and Criticality Analysis of the Saturn IB, IU Stage," Parts I and II, July 1965.

94. GE/ASD, RAU7, "Electrical Support Equipment Failure Effect and Criticality Analysis of the Saturn IB, Power," Parts I and II, August 1965.

95. GE/ASD, RAU8, "Electrical Support Equipment Failure Effect and Criticality Analysis of the Saturn IB, System Integration," August 1965.

96. GE/ASD, "Saturn IB Electrical Support Equipment Reliability Analysis Report," August 1965.

97. GE/ASD, "Reliability Program Plan for Electrical Support Equipment," Rev. A, February 1965.

98. GE/ASD, NASw 410-40-13-32, "ACE-S/C Reliability Quarterly Status Report, Second Quarter 1965," 15 July 1965.

99. GE/ASD, NASw-410-Exhibit A, Section II, Paragraph B1.2.1 "Weekly Status Report," Week of 30 August 1965.

100. GE/ASD, NASw-410, "Minutes of Status and Design Review Meeting No. 18," 12 August 1965.

101. GE/ASD, TIR 544-096-5070, "Analysis of CSM-009 Certification Test Status," 16 July 1965.

102. GE/ASD, ASD-QA-09-65-1, "Gemini Spacecraft Malfunction Summary Review Issue No. 4" (and previous issues), 1 September 1965.

103. GE/ASD, ASD-MR-04-65-2, "Mission Reliability and Safety Analysis Work Plan," Contract NASw-410, 14 April 1965.

104. GE/ASD, ASD-MR-07-65-30, "Apollo-Saturn 201 Mission Success Computations (U)," 16 July 1965, CONFIDENTIAL.

105. GE/ASD, ASD-MR-09-65-6, Class III, "Apollo-Saturn 201 Mission Contingency Considerations," 17 September 1965.

106. GE/ASD, ASD-MR-09-65-30, Class III, "Spacecraft 009 Prediction Reliability Report (U)," 22 September 1965, CONFIDENTIAL.

107. IBM, 62-382-0011H, "Saturn Instrument Unit Mission, Reliability and Part Program Plan," 19 October 1964.

108. IBM, "Preliminary Failure Mode, Failure Effect, and Criticality Analysis for S-IU-201," 23 May 1965.

109. IBM, 64-382-0010H, "Saturn V Mod II Redundant Switch Selector Reliability Program Plan," Supplement, 5 November 1964.

110. IBM, "Saturn IU Mission Program, Quarterly Technical Review," 12 August 1965.

111. IBM, 65-208-0019H, "Saturn Instrument Unit Test Status Chart," Vol. I, 1 August 1965.

112. IBM, 65-966-0010H, "Saturn Instrument Unit Mission Monthly Progress Report," 27 July 1965.

113. IBM, 65-928-57, "Saturn V, Launch Vehicle Digital Computer and Data Adapter Prototype Program Monthly Progress Report," June 1965.

114. IBM, "Saturn IB/V, Launch Vehicle Digital Computer and Data Adapter Flight Model Program Monthly Progress Report," June 1965.

115. IBM, "Monthly Quality Status Report," June 1965.

116. NAA/S&ID, SID-62-203, "Apollo Reliability Program Plan (U)," 29 May 1964, CONFIDENTIAL.

117. NAA/S&ID, "List of Procurement Specifications S/C and GSE Reliability Objectives," 18 May 1965.

118. NAA/S&ID, SID-62-557-5, "Quarterly Reliability Status Report (U)," 31 May 1963, CONFIDENTIAL.

119. NAA/S&ID, SID-62-557-9, "Quarterly Reliability Status Report (U)," 30 April 1964, CONFIDENTIAL.

120. NAA/S&ID, SID-62-557-11, "Quarterly Reliability Status Report (U)," 30 September 1964, CONFIDENTIAL.

121. NAA/S&ID, SID-62-557-12, "Quarterly Reliability Status Report (U)," 31 December 1964, CONFIDENTIAL.

122. NAA/S&ID, SID-62-557-13, "Quarterly Reliability Status Report (U)," 30 April 1965, CONFIDENTIAL.

123. NAA/S&ID, SID-62-557-14, "Quarterly Reliability Status Report (U)," 31 July 1965, CONFIDENTIAL.

124. NAA/S&ID, SID-64-2114, "Vehicle Test Plan Apollo Mission A-202," 15 December 1964.

125. NAA, SID-62-128, "Saturn S-II Reliability Plan, 28 April 1964.

126. NAA, SP65-23, "S-II Quarterly Review Qualification Status Report," May 1965.

127. NAA, 65-692-400-07, "Certification Test Network Monthly Requirements Report," 1 July 1965.

128. NAA, 65-692-500-009, " Certification Test Network for SC-009," 1 April 1965.

129. NAA Rocketdyne, R-3374-45, "H-1 Informal Technical Progress Report," July 1965.

130. NAA Rocketdyne, R-5456-4, "H-1 Engine Program Semiannual Report, Summary of Development," February thru July 1965.

131. NAA Rocketdyne, "J-2 Engine Technical Program Review," 13 September 1965.

132. NAA Rocketdyne, "Quality Control Monthly Reports," June and July 1965.

133. NAA/S&ID, "Apollo Monthly Quality Status Report," June 1965.

134. NAA/S&ID, "Monthly Progress Report." June 1965.

135. Nortronics, "Progress Report," NASA Contract NAS8-13008, 15 July 1965.

136. Nortronics, "Progress Report," NASA Contract NAS8-13008, 20 August 1965.

137. GE/ASD, MR-05-65-2, "Design Reference Mission Reliability Profile (Draft)(U)," Class III, 28 May 1965, CONFIDENTIAL.

APPENDIX B
LIST OF ABBREVIATIONS AND CODES

ACE - Acceptance Checkout Equipment
ACED - AC Electronics Division
AMPTF - Apollo Mission Planning Task Force
APIC - Apollo Parts Information Center
APO - Apollo Program Office
APS - Auxiliary Propulsion System
ASPO - Apollo Spacecraft Program Office
ATR - Apollo Test Requirements

BP - Boiler Plate Spacecraft

CCSD - Chrysler Corporation Space Division
CDR - Critical Design Review
CM - Command Module
C/O - Checkout
COFW - Certification of Flight Worthiness
CSM - Command/Service Module
CTN - Certification Test Network

DAC - Douglas Aircraft Company
DDAS - Digital Data Acquisition System
DEI - Design Engineering Inspection
DRM - Design Reference Mission

EBW - Exploding Bridge Wire
ECP - Engineering Change Proposal
ECS - Environmental Control Subsystem
EDS - Emergency Detection System
ELS - Earth Landing Subsystem
EPS - Electrical Power Subsystem
EMC - Electromagnetic Compatibility
EMI - Electromagnetic Interference
ESE - Electrical Support Equipment
ESI - Electronic System Integration
ETR - Eastern Test Range

FEA - Failure Effects Analysis
FEAT - Final Engineering Acceptance Test
FMEA - Failure Mode Effects Analysis
FMECA - Failure Mode Effects and Criticality Analysis
FRR - Flight Readiness Review
FRT - Flight Readiness Test
FTA - Flight Test Article

GA - Government Agency
GAEC - Grumman Aircraft Engineering Corporation
GE/ASD - General Electric Company/ Apollo Support Department
GFE - Government Furnished Equipment
G&N - Guidance and Navigation
GOSS - Ground Operational Support System
GSE - Ground Support Equipment
GSFC - Goddard Space Flight Center

IBM - International Business Machines Corporation
IMU - Inertial Measurement Unit
IU - Instrument Unit

KSC - Kennedy Space Center

LC - Launch Complex
LCC - Launch Control Center
LEM - Lunar Excursion Module
LES - Launch Escape Subsystem
LH_2 - Liquid Hydrogen
LJ - Little Joe Launch Vehicle
LN_2 - Liquid Nitrogen
LOR - Lunar Orbital Rendezvous
LOX - Liquid Oxygen
LTA - LEM Test Article

LUT - Launcher - Umbilical Tower
LVDA - Launch Vehicle Data Adapter
LVDC - Launch Vehicle Digital Computer

MCC - Mission Control Center
MDS - Malfunction Detection System
MILA - Merrit Island Launch Area
MIT - Massachusetts Institute of Technology
MLL - Manned Lunar Landing
MRB - Material Review Board
MSC - Manned Spacecraft Center
MSF - Manned Space Flight
MSFC - Marshall Space Flight Center
MSFN - Manned Space Flight Network
MTBF - Mean Time Before Failure

NAA - North American Aviation, Inc.
NASA - National Aeronautics and Space Administration
NMI - NASA Management Instructions
NPC - NASA Publication Control (number)

ODOP - Offset Doppler Electronic Tracking System
OMSF - Office of Manned Space Flight

PCM - Pulse Code Modulation
PDP - Program/Project Development Plan
PERT - Program Evaluation Review Technique
P/N - Part Number

RCA - Radio Corporation of America
RCS - Reaction Control Subsystem
R&D - Research and Development
RFI - Radio Frequency Interference
RFP - Request for Proposal
R&QA - Reliability and Quality Assurance

SA - Saturn Apollo
SACTO - Sacramento Test Operation
SC - Spacecraft
SCS - Stabilization and Control Subsystem
S&ID - Space and Information Systems Division of NAA
SLA - Spacecraft - LEM Adapter
SM - Service Module
SPFS - Single Point Failure Summary
SPS - Service Propulsion Subsystem
STL - Space Technology Laboratory

TM - Test Module

UHF - Ultra High Frequency
ULD - Unit Logic Device

VAB - Vehicle Assembly Building
VHF - Very High Frequency

WSMR - White Sands Missile Range